AD A089737

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14

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-TR-1925	2. GOVT ACCESSION NO. AD-A089737	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) An Equivalent Transportation Vibration Test—Procedures and Techniques Applicable to the Army M732 Field Artillery Fuze		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Abraham M. Frydman, Frank L. Tevelow		8. CONTRACT OR GRANT NUMBER(s) 12 112
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 11
11. CONTROLLING OFFICE NAME AND ADDRESS Army Materials and Mechanics Research Center, Watertown, MA 02172		12. REPORT DATE June 1980
		13. NUMBER OF PAGES 110
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

AD-A089737

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

DRCMS Code: 53970M6350

HDL Project: 852685

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Direct digital computer control
Sine/random vibration testing
Simulation
Equivalent testing
Transportation vibration testing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

→ A random vibration (RV) test in the 5- to 500-Hz range is proposed as a replacement for the MIL-STD-331, Method 119, standard swept sinusoidal transportation vibration (TV) test (5 to 500 Hz, 5 g peak) currently used for lot acceptance testing of M732 fuze safety and arming (S&A) production modules. The objective of this Materials Test Technology (MTT) project is to establish RV test criteria that will produce "damage" to the S&A module equivalent to

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143

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20. Abstract (cont'd)

that incurred in the standard TV test, but to do so in a manner more consistent with field-imposed TV conditions and to do so in a much shorter test period.

One hundred units of the M732 S&A's were taken from a standard lot and set aside for this project. The criteria established for damage equivalency evaluation were post-test operability (turns-to-arm--TTA), visual inspection, dimensional measurements, and chemical-mechanical analysis. Also, information was obtained regarding module response to vibration and frequency sub-bands to which the module or its component parts are most sensitive. The information resulted from use of a triaxial accelerometer and a strain gage mounted on the module, and by an isolation-mounted acoustical pickup. Data from the first two transducers were analyzed in detail by use of computerized spectral analysis methods.

Predictions of a 60-percent reduction in test time came about through empirical evaluation of the number of reversal cycles per sweep cycle for the standard TV test and mathematical analysis based on "false alarm" noise theory. RV tests at 5, 10, 15, and 20 g rms for 20 min/axis bracketed damage (ascertained by TTA and visual inspection) achieved in the standard test in a 4-hr period. Acoustical test data and spectral analysis results indicated most activity (thus damage) occurred in the 50- to 250-Hz sub-band. Narrower activity sub-bands were also determined, but because of the specific scope of the project, these observations were not verified as to the specific cause. Other definitive conclusions were that lubrication of units was a very important determinant in affecting final damage, and that transverse vibration was a more severe test than axial vibration. Additional tests and evaluations must be performed to finalize specific parameters regarding envelope shape for RV testing, spectral amplitudes, and corresponding test time duration per axis.

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

Page

FIGURES

CONTENTS (Cont'd)

Page

TABLES

1. INTRODUCTION

The standard transportation vibration (TV) test for qualification of ordnance fuze materiel currently invokes a swept sinusoidal frequency spectrum to drive an electrodynamic shaker, upon which the test unit is mounted. Specific frequency and time conditions are imposed by MIL-STD 331, Method 119. Procedure I of this test calls for a sinusoidal sweep covering 5 to 500 Hz at a rate of 1 cycle (5→500→5 Hz) per hour, with four such cycles applied consecutively in each of three mutually perpendicular directions. One axis must be coincident with the longitudinal fuze axis; the total test time is 12 hours. (Procedure II of the test is similar but mandates 2 hours of testing per axis for a total test duration of 6 hours.)

Basically, MIL-STD 331, Method 119, has been the standardized TV fuze validation and lot acceptance procedure for more than two decades. Even so, it should be noted that the test itself evolved as a convenient TV criterion; it specified test conditions that could be described precisely and duplicated readily at a variety of installations; thus, tests done anywhere provide similar data. It should also be noted that the standard test made no attempt to "simulate" actual field TV conditions since the real environment in almost all instances consists of a random vibration spectrum rather than the specified discrete sinusoidal sweep.

Although the TV test has provided a somewhat adequate validation criterion, it does have technical deficiencies, and the test procedure itself is time-consuming and costly. In considering methods to reduce test time and cost without impairing test effectiveness, a more realistic simulation method was proposed; it would implement the random vibration aspects of the real environment, concentrate the test spectrum in the frequency range that was deemed to be most injurious to the unit being tested, and, most important, it would shorten the test time. Test criteria were to be established theoretically and verified experimentally. Damage equivalency was to be determined by a comparison of the results obtained on M732 safety and arming (S&A) units tested by the TV procedure with results on similar units tested by the proposed random TV (RTV) test. It was also proposed that, at a later date, the procedure would be refined by evaluation of field-recorded TV data and that test criteria would be updated on both the RTV spectrum and the required test time duration.

A discussion of background theory, procedures, instrumentation, test data, and analysis of test results follows.

2. PROGRAM PLAN

Although no investigation was made for this report as to how the swept sinusoidal MIL-STD test was designed or originally formulated, its continued use suggests that it has served its purpose in providing reliable ordnance units, despite the drawbacks previously mentioned.

Even though the standard test's relevancy to the "real world" TV environment is unknown, the initial step in establishing the validity of the proposed RTV test method was the intention of showing the equivalence of the two test methods in terms of their damage potential to ordnance materiel. The item selected for this purpose was the S&A unit from the M732 fuze — a device designed, engineered, and brought into production by Harry Diamond Laboratories (HDL) engineers.

The "equivalency" concept was quite simple: sample units were run using the standard TV test criteria as controls, then other units were subjected to random TV testing for comparison and evaluation. A basic criterion (evaluation parameter) was to be the number of turns required to arm the S&A unit, a standard acceptance measure. This test was run on all units before and after the TV tests. Additional quantitative data on "damage" were to be obtained by visual inspection and sophisticated dimensional measurements, as well as by chemical cleaning, analysis, and weighing of post-test particulate matter within the S&A units.

Establishing the criteria for the RTV test was another phase of the program plan. The initial spectral content of the RTV was to have a constant average amplitude and cover the 5- to 500-Hz band, the same range as the TV test. Test duration per axis was predicated on causing the same number of reversible cycles ($\sim_R$) in the random test as exists in the standard TV test specifications. An equivalent number of $\sim_R$ was determined mathematically and verified by an analysis of RTV tests spectra. The drive level for RTV was to be determined experimentally by tests at various g amplitudes and by an analysis of damage sustained by the S&A units.

Additional research investigated the underlying fundamentals of damage criteria, both in the design of TV tests and the very specific, individual construction of ordnance materiel. This phase was pursued by way of several approaches. The basic method involved sinusoidal vibration of the S&A unit and transducer response measurements of the S&A cover plate to detect vibration modes and sub-bands of maximum displacement activity. This test also used an isolated (physically decoupled) microphone to record corresponding acoustic data. Finally, these data records were computer analyzed to yield power spectral density as a function of input drive signal frequency. Analyses of these data will provide the ground work for subsequent definition of RTV test procedures, based on additional testing (proposed as a continued effort).

3. M732 S&A MODULE

3.1 Selection of Test Unit

The S&A module for the M732 fuze, designed and engineered at HDL, was selected as the test unit for evaluation of comparative damage effects sustained as a result of either the standardized TV test or the proposed RTV test. This choice was dictated by the expertise available at HDL for consultation and analysis of test data results and by the pertinent feedback loop that would make relevant test data readily available to the S&A designers.

The specification control drawing for the S&A module, part number (PN) 11716741 is shown in figure 1. Figure 2 is a cutaway view of the M732 fuze, showing the S&A module.

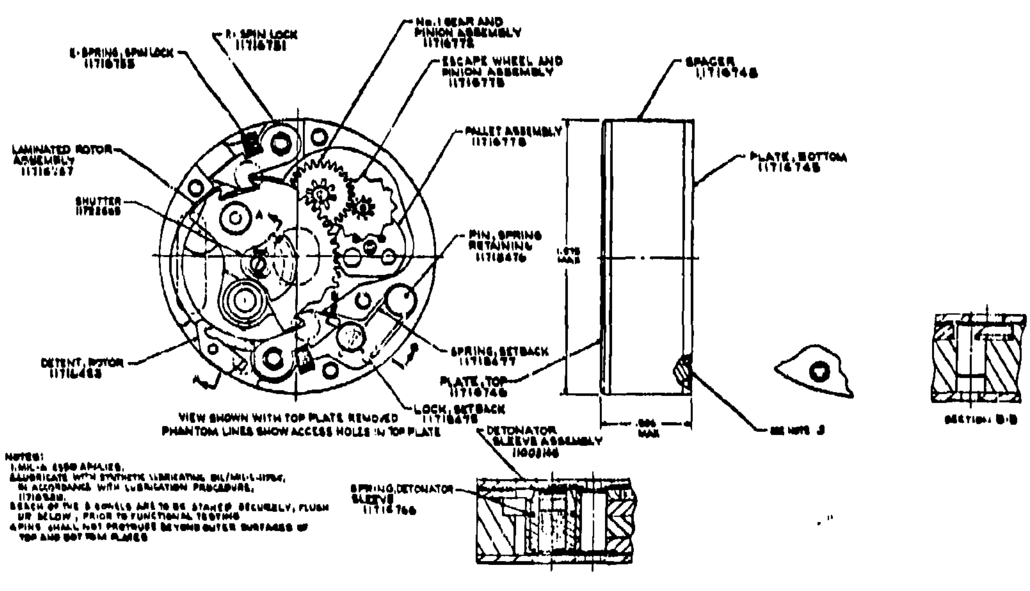


Figure 1. Specification control drawing for S&A module, PN11716741.

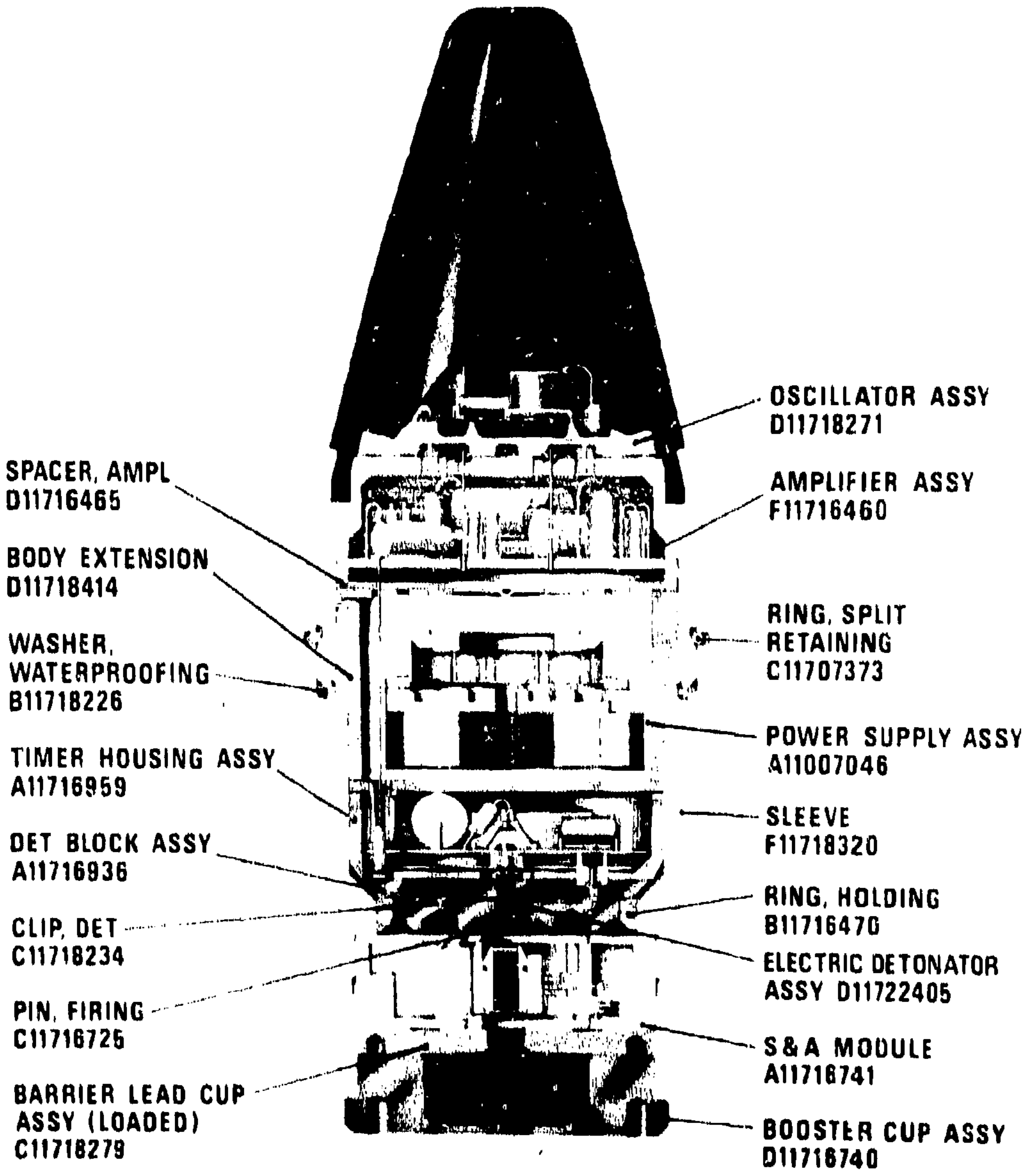


Figure 2. M732 Fuze — cutaway view showing S&A module.

One hundred of the S&A modules, PN11716741, serial numbers F-1 through F-100 were obtained for this program. These modules were standard lubricated units taken from production lot WTX-2-2, manufactured by the General Time Co.

3.2 S&A Module Arming Specifications

Upon receipt by HDL, all modules had their detonators removed and replaced by a dummy detonator. Units were then run on a spinner (manufactured by Delaware Valley Armament, Inc.), that complied with the PN11716741 Specification Control Drawings (SCD). The following information is from paragraph number 4.5.2.1. (in part).

> "Spin Equipment. The equipment used for the arming tests shall be designed to position the rotor of the module in the fully out-of-line position automatically and shall provide positive indication when the rotor is released. This position indication shall serve as the starting signal for determining the number of turns-to-arm (TTA) ...."

SCD acceptance criteria specify that units are to arm between 25 and 38 turns as follows, from paragraph 3.3.1.1 of the SCD's.

> "Arming. With the setback lock in the armed position, the rotor in the S&A module shall fully arm within the limits of 25 to 38 revolutions of theS&A module when spun at 2500 rpm...."

TTA was a critical test measurement since it was a control reference that served as a baseline criteria for assessing the effect of subsequent tests performed on sample units.

4. PROPOSED TEST METHOD

4.1 Equivalency Criteria/Determination

Random and sinusoidal vibrations are fundamentally quite different, both in their mathematical formulation and in their engineering implications. In testing, dynamic vibratory excitation can be imparted to a test specimen with either type of drive, although swept frequency sinusoidal testing has been more prevalent.

Random vibration usually exhibits a normal (Gaussian) distribution around a mean value, with a specific standard deviation associated with its distribution. This statistical property ensures that random vibrations are nondeterministic — namely, that the instantaneous magnitude of the vibrations cannot be determined in advance. A swept sinusoidal excitation, by contrast, is deterministic, since it results from the synthesis of single-valued amplitude/frequency components with discrete frequency-time relations defined by the prescribed test spectrum and sweep rate.

Although mathematical approximations and models may be used to relate sinusoidal and RTV test procedures and test results, a realistic, practical assessment of the two test methods must be made by an evaluation of wear and tear on test items. That is, the true equivalence between the two drive methods can only be assessed with respect to the actual, intrinsic damage potential of each method. The amount of vibratory wear damage and the criteria for establishing a reduced RTV test time are postulated to be dependent on the total number of $\sim_R$ accumulated during the standard swept sinusoidal TV test. If an average $\sim_R$ per unit time, of given magnitude, can be established for the specified random vibrations, then the estimated new test time would be equal to the standard TV total number of $\sim_R$ divided by the corresponding time averaged random $\sim_R$. Fine adjustment to this estimated test time could then subsequently be made on the basis of actual damage assessment on sample test units.

A description of the MIL-STD 331, Method 119, Procedure II TV test is given in section 4.2, together with a determination of the total number of $\sim_R$ for this method in 4.3. This is followed by experimentally and theoretically determined values for $\sim_R$ in RTV testing in sections 4.5 and 4.6, respectively. Results indicate that the 4-hour TV test time can be reduced to a 1.6-hour RTV test equivalent.

4.2 MIL-STD 331, Method 119, Procedure II TV Test

The standard TV test, according to MIL-STD 331, Method 119, Procedure II, invokes a sinusoidal sweep between 5 and 500 Hz at a rate of 1 cycle (5→500→5 Hz) per hour (fig. 3) over a period of 2 hours per axis for a total duration of 6 hours. Amplitude-frequency characteristics are shown in figure 4. It should be noted that amplitude criteria are specified as a displacement between 5 and 11 Hz and 37 and 52 Hz and as an acceleration elsewhere.

4.3 Total Number of $\sim_R$ in Standard Test

The total number of $\sim_R$ accumulated per sweep cycle for each of three mutually independent axes of the S&A module is established as follows (for simplicity, all frequency components were considered to be of equal magnitude, i.e., 5 g.).

$$\log f_1 = \log A + mt_1 \quad . \tag{1a}$$

$$\log f_2 = \log A + mt_2 \quad . \tag{1b}$$

The boundary conditions are

$$f_1 = 5 \text{ Hz} \quad , \qquad f_2 = 500 \text{ Hz} \quad .$$

and

$$t_1 = 0 \text{ hr} \quad , \qquad t_2 = 0.5 \text{ hr} \quad .$$

Hence,

$$\log(f_1/A) = mt_1 = 0 \quad ,$$

$$f_1/A = 1 \quad ,$$

$$A = 5 \text{ Hz} \quad .$$

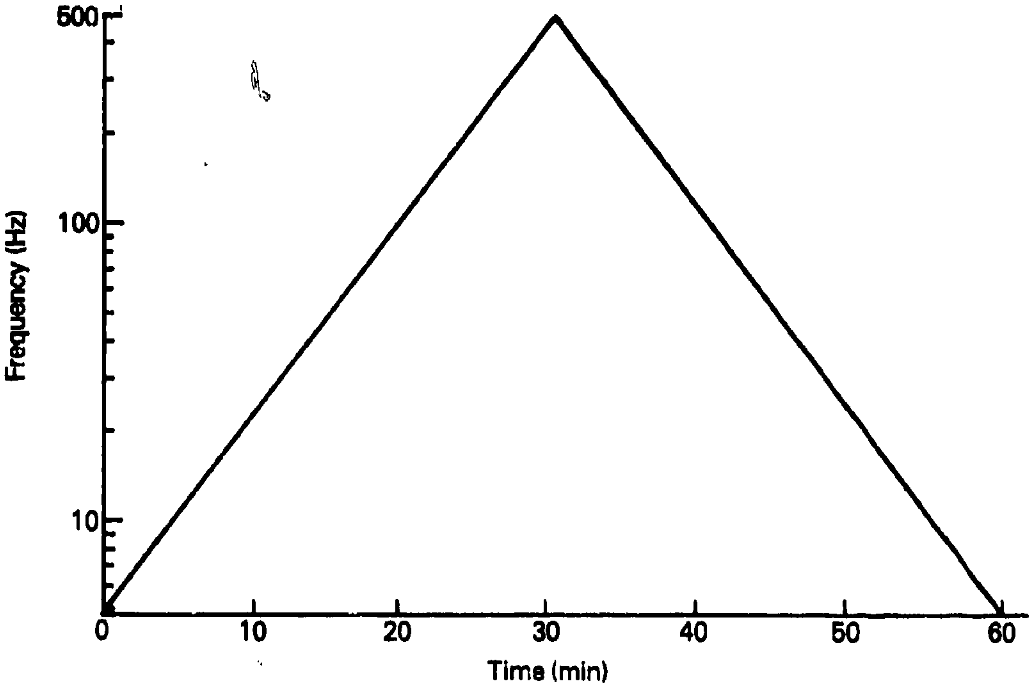


Figure 3. MIL-STD 331, Method 119, transportation vibration sinusoidal sweep cycle.

And

$$\log(f_2/A) = mt_2 \quad ,$$

$$\log(f_2/A) = \log \frac{500}{5} = 2 \quad ,$$

$$mt_2 = 2 \quad , \qquad m = 2/0.5 \quad ,$$

$$\text{and } m = 4 \text{ hr}^{-1} \quad .$$

Substituting $f_1 = f_o$ and $f_2 = f$ in equations (1a) and (1b), then subtracting equation (1a) from equation (1b), the following is obtained.

$$\log(f/f_o) = mt$$

and

$$f(t) = f_o\ 10^{mt} \text{ Hz} \qquad (2)$$

Equation (2) establishes the instantaneous value of the test frequency anywhere in the one-half sweep cycle ($0 \leq t \leq 30$ min); outside this time band, mirror images of this relationship exist as shown in figure 3.

Let an incremental number of cycles accumulated during the sinusoidal sweep test equal dN; f(t) denotes a time-dependent frequency component and dt denotes incremental time. Thus,

$$N = \int_o^\tau f(t)dt$$

$$= f_o \int_o^\tau 10^{mt} dt \quad . \qquad (3)$$

To evaluate this integral, let $y = 10^{mt}$. Then

$$\ln y = mt \ln 10 \quad ,$$

$$y = e^{(m \ln 10)t} = 10^{mt}, \text{ and} \qquad (4)$$

$$y = e^{at} \quad ,$$

where $a = m \ln 10$.

Substituting for 10^{mt} into the above integral (eq 3) yields

$$N = f_o \int_o^\tau e^{at}\, dt$$

$$= f_o \int^\tau \frac{d}{dt}\left(\frac{1}{a}\, e^{at}\right)$$

$$= \frac{f_o}{a}(e^{at} - 1) \qquad (5)$$

Substituting back for a in the exponential term, quantity N is given by

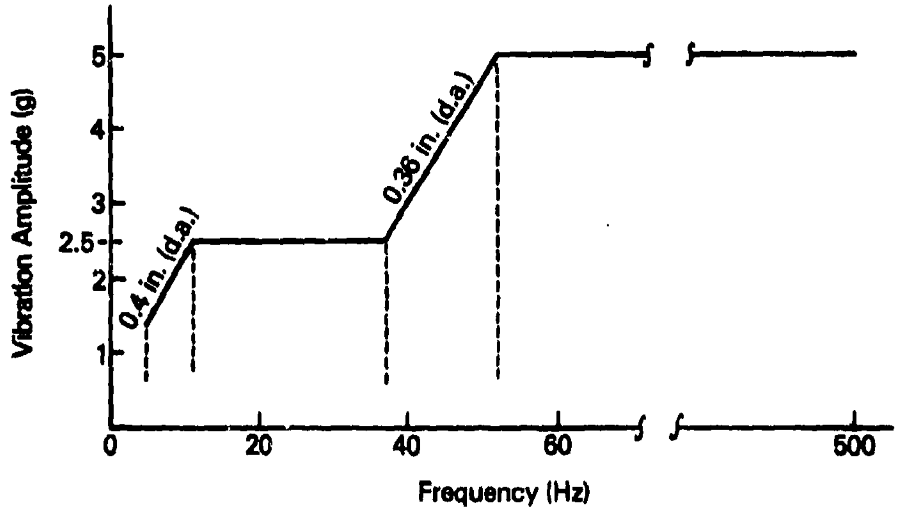


Figure 4. MIL-STD 331, Method 119, transportation vibration sinusoidal sweep spectrum.

$$N = \frac{f_o}{m \ln 10}\left(10^{mt} - 1\right) . \qquad (6)$$

For MIL-STD 331, Method 119, Procedure II, $t = 0.5$ hr, $f_o = 5$ Hz, and $m = 4\ \mathrm{hr}^{-1}$. Substituting into equation (6) for N yields

$$N = \frac{5(\sim/\mathrm{s}) \times 3600(\mathrm{s/hr})}{4(1/\mathrm{hr}) \times \ln 10}$$

$$\left[10^{4(1/\mathrm{hr})\,(1/2\ \mathrm{hr})} - 1\right]$$

$$N = 193{,}478 \sim_R /\text{half-cycle sweep}.$$

Since the sweep rate is 1 cycle/hr and the total test time that will be used for damage assessment is 4 hr/axis,* the total number of reversible cycles per test axis (x, y, and z) is equal to N_{Tot},

$$N_{Tot} = 193{,}478\ \frac{\sim_R}{\text{half-sweep cycle}} \times \frac{2\ \text{half-sweep cycles}}{\text{hr}} \times \frac{4\ \text{hr}}{\text{test-axis}}$$

$$N_{Tot} = 1{,}547{,}830$$

$$N_{Tot} \approx 1.55 \times 10^6\ \frac{\sim_R}{\text{test-axis}} .$$

A computer program was written to establish the numerical values of parameters f, N, and N_{Tot} as functions of test frequency and time. The program, a tabular listing presented in Appendix A, shows the instantaneous numerical value of each of the parameters over 1-minute intervals within the 240-minute range and graphical plots of the sweep function and N_{Tot}.

*The more rigorous criterion for development testing calls for 4 hours of testing per axis (MIL-STD 331, Method 119, Procedure I); Production testing per Procedure II calls for 2 hrs/axis; N = 775,000 reversible cycles/test-axis for Procedure II, and 1,550,000~R/test-axis for Procedure I.

4.4 Reversible Cycles in RTV Testing

To determine the equivalent test time for the proposed RTV test, a statistical cycle-reversal frequency about a specified mean or rms level of excitation had to be established. This was achieved in two independent ways — through evaluation of test data and by theoretical considerations.

4.5 Experimentally Determined $\sim_R$

The electrodynamic shaker was excited continuously for a total of 30 minutes by a flat random vibration spectrum (5 to 500 Hz) of magnitude 0.18 g^2/Hz (9.43 g rms). The shaker excitation was recorded on magnetic tape and then reproduced on high-resolution chart paper played back at 80 in./s. Time spans of 0.1 s were selected from each one of the 1-minute vibration data records. The selected increments were then visually scanned and the number of $\sim_R$ larger than 10 percent of the positive and negative peak test amplitude (±3 estimated standard deviations) were counted. (This is equivalent to counting only positive slope signals exceeding the +10 percent threshold value.) For convenience, the mean value of the signal was considered as zero reference and the 0.1-s increments selected were chosen to expedite the evaluation process. A typical record is shown in figure 5. Results are shown in table 1.

The mean number of reversals in 0.1 s, f is equal to

$$f = \frac{1}{N} \sum_{i=i_o}^{i_o+N} f_i = 1/30 \sum_{i=0}^{29} f_i = 775/30 ,$$

and

$$f = 25.8 \text{ reversals}/0.1 \text{ s} .$$

Since the frequency components are assumed to be randomly distributed, the standard deviation of the frequency data follows the normal distribution curve; i.e.,

$$\sigma_f^2 = \frac{1}{N-1} \sum_{i=o}^{N-1} (f_i - f)^2 \quad ,$$

$$\sigma_f^2 = \frac{1}{29} \quad (172.2) = 6.15 \quad ,$$

$$\text{and } \sigma_f = 2.48 \quad .$$

Hence, the 3-sigma band around f is

$$f_{max} = f + 3\sigma_f = 33.2$$

$$f_{mean} = f = 25.8$$

$$f_{min} = f - 3\sigma_f = 18.3$$

Using f_{mean} equal to 25.8 and extrapolating the results to one second of data, this value becomes

$$F = \frac{25.8}{0.1} = 258 \ \sim_{R/s}$$

Hence an equivalent random vibration test time, T, is obtained by dividing the number of accumulated $\sim_R$ by the average rate (frequency) of cycle reversals. Thus,

$$T = \frac{N_{Tot}}{F} = \frac{1{,}548{,}000 \ \sim_R}{258 \ \sim_{R/s} \times 3600 \text{ s/hr}} = 1\text{-}2/3 \text{ hr}$$

4.6 *Equivalent Test Time — Mathematically Determined*

The total number of expected crossings of a specified amplitude level (T_1) can be obtained from the formula which defines the alarm (false signal) rate in terms of threshold crossing. That is,

$$F_1(T_1) = \frac{1}{2\pi} \left| \frac{W_n(o)}{W_n(o)} \right|^{1/2} e^{-\left[\frac{T_1^{\,2}}{2W_n(o)}\right]} \quad ,$$

where

F_1 = number of signals exceeding the threshold value in cycles/s,

T_1 = arbitrary reference threshold level,

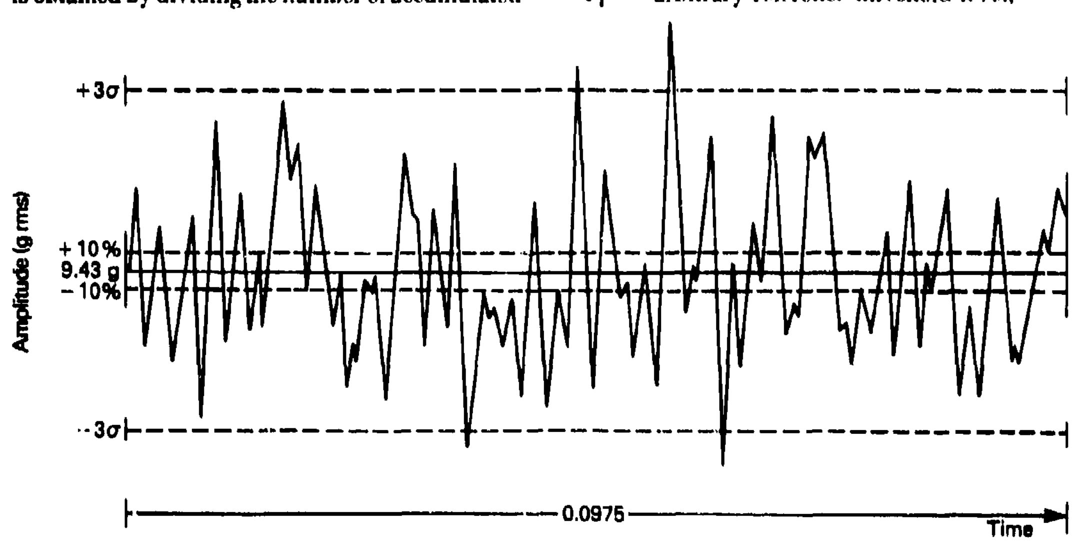


Figure 5. Reproduction of tape record taken at 80 in./s paper speed. (shown above is representative sample from 0.1-s raw data slice). Amplitude is shaker response to broadband random vibration drive (bandwidth 5→500 Hz). Reversal cycles (see text) for 0.1 s ≈ 24; crossings/s ≈ 240.

TABLE 1. NUMBER OF REVERSIBLE CYCLES IN 0.1-S SPANS FOR A 30-MIN RANDOM VIBRATION SHAKER TEST

Count	Test time (min)	f_i ~R ≥ 10% peak amplitude per 0.1-s interval	$f_i-\bar{f}$	$(f_i-\bar{f})^2$
0	1	26	0.20001	0.0400003
1	2	24	−1.8	3.24
2	3	32	6.2	38.44
3	4	27	1.2	1.44
4	5	24	−1.8	3.24
5	6	25	−0.799999	0.639999
6	7	24	−1.8	3.24
7	8	25	−0.799999	0.639999
8	9	25	−0.799999	0.639999
9	10	24	−1.8	3.24
10	11	27	1.2	1.44
11	12	27	1.2	1.44
12	13	30	4.2	17.64
13	14	26	0.200001	0.0400003
14	15	27	1.2	1.44
15	16	27	1.2	1.44
16	17	21	−4.8	23.04
17	18	26	0.200001	0.0400003
18	19	27	1.2	1.44
19	20	23	−2.8	7.84
20	21	27	1.2	1.44
21	22	25	−0.799999	0.639999
22	23	27	1.2	1.44
23	24	26	0.200001	0.0400003
24	25	31	5.2	27.04
25	26	23	−2.8	7.84
26	27	21	−4.8	23.04
27	28	26	0.200001	0.0400003
28	29	26	0.200001	0.0400003
29	30	26	0.200001	0.0400003
$N = \sum_i = 30$		$\sum_{i=0}^{29} f_i = 775$		$\sum_{i=0}^{29} (f_i - \bar{f})^2 = 172.2$

W_o = constant level of autocorrelation function,

$\ddot{W}(o)$ = second derivative of the autocorrelation function evaluated at zero,

$W(0)$ = autocorrelation function evaluated at zero,

f = test frequency — Hz, and

f_m = maximum test frequency — Hz.

For convenience in the computations, let $T_1 = 0$, and let the power spectral density of the random vibration be band-limited white noise between 5 and 500 Hz. Evaluating the parameters,

$$\ddot{W}_n(o) = -4\pi^2 \int_0^\infty f^2 W_n(f)df .$$

Since $W_n(f)$ is a constant for limited white band noise,

$$\ddot{W}(o) = -4\pi^2 W_o \int_0^{f_m} f^2 df = -\frac{4}{3} \pi^2 f_m^3 W_o .$$

The correlation function is related to the power density spectrum by the Wiener-Khinchin theorem.

$$W_n(\tau) = \int_0^\infty W_n(f) \cos 2\pi f\tau df ,$$

$$W_n(\tau) = W_o \int_0^{f_m} \cos 2\pi f\tau df = \frac{W_o \sin 2\pi f_m \tau}{2\pi\tau} .$$

$$\text{Let } D\left[W_n(o)\right] = \lim_{\tau \to o} \frac{\cos (2\pi f_m \tau) 2\pi f_m}{2\pi}$$

and in the limit as $\tau \to o$

$$W_n(o) = W_o f_m$$

Substituting back into the autocorrelation equations in the main expression,

$$F_{1(\tau_1 = o)} = \frac{1}{2\pi}\left[\frac{\left|-4\pi^2 f_m^3 W_o\right|}{3 f_m W_o}\right]^{1/2}$$

$$= \frac{f_m}{\sqrt{3}} = 0.577 f_m .$$

Since $f_m = 500$ Hz ,

$F_{1(T_1 = o)} = 289$ Hz .

Hence, the crossing frequency above reference level $T_1 = 0$, whether viewed from either the positive or negative directions, is equal to 288 Hz. This compares fortuitously well with the test-established results, which yielded a value of 258 Hz. These results lend further credence for the proposed test time, as specified in section 4.1.

5. TEST PROCEDURE

The basic experimental TV environment test consisted of running either the MIL-STD 331, Method 119, Procedure I, TV test, or the RTV test (at one of four g levels). A breakdown of the tests run on specific modules is shown in table 2. A total of 15 units were exposed to the TV test (baseline, sinusoidal, groups 1 and 2); this consisted of 4 hours of testing along each of three mutually perpendicular axes (a total of 12 hours). A curve of amplitude (acceleration) versus sinusoidal sweep range of 5 to 500 Hz is shown in figure 4; a plot of test frequency versus time is shown in figure 3. Four groups (numbers 3 through 6) of three units each were subjected to the RTV (also 5 to 500 Hz) for 20 minutes along each of three mutually perpendicular axes (1 hour total), at constant average acceleration levels of 5, 10, 15, and 20 g rms.

These tests were run to evaluate the effect of the specific vibratory environments in terms of damage (wear, abrasion, and distortion) of module parts, and operational characteristics (TTA). The immediate objective was determination of an equivalency between TV tests and RTV tests; the g parameter was introduced into the RTV tests to produce a test-time duration factor, on the assumption that the product of vibratory amplitude, reciprocal test time, and a proportionality parameter would approximate a constant value.

TTA tests were run on each sample subsequent to vibratory testing. Units were then disassembled and observed visually for obvious signs of abrasion, scuffing, and distortion of parts or holes. In addition, particular attention was addressed to the amount of lubricating oil that was present, its coloration, consistency, and the apparent presence and amount of metal particles. At best, such determinations were qualitative and only of relative value. However, these observations led to subsequent development of a chemical/mechanical metal separation process, capable of providing a quantitative determination of the weight of large and fine particles ("fines"). Subsequent to this analysis, components were viewed with a microscope (50 X and 100 X) to obtain a quantitative measure of dimensional changes.

5.1 Baseline Testing Criteria

Any RTV test method that would be acceptable initially as a replacement for the standard TV test would have to demonstrate damage that would be similar (equivalent) to results established during lease-line (standard testing). Baseline testing was therefore used to establish mechanical damage criteria and parameters against which all samples from subsequent tests would be compared for damage evaluation. Damage criteria were evaluated as described in the following paragraphs.

5.1.1 S&A Turns-To-Arm

The M732 S&A module functional arming time (TTA) was to be determined using the 2500-rpm spinner; test samples were subjected to fuctional arming-time tests before and after a given vibration

TABLE 2. IDENTIFICATION OF S&A MODULES IN BASELINE AND RANDOM TRANSPORTATION VIBRATION TESTS

Group	S&A module serial no.	Test spectrum	Total test time (hr)
1	F-1 through F-8	MIL-STD-331, Method 119, Procedure 1	12
2	F-9 through F-16	Same as above	12
3	F-18 F-19 F-20	Random vibration 5 g rms, 0.0505 g^2/Hz, 5 to 500 Hz, 20 min/axis	1
4	F-21 F-22 F-23	Random vibration 10 g rms, 0.202 g^2/Hz, 20 min/axis	1
5	F-26 F-27 F-30	Random vibration 15 g rms, 0.4545 g^2/Hz, 5 to 500 Hz, 20 min/axis	1
6	F-17 F-28 F-29	Random vibration 20 g rms, 0.80 g^2/Hz, 5 to 500 Hz, 20 min/axis	1

test. Any degradation in arming time, manifested in the form of delayed function, would be indicative of damage sustained during the test. This test is significant because it provides quantitative data.

5.1.2 Inspection Measurements

Post-test disassembly of the S&A module allows detailed inspection and examination of all internal components so as to determine the location, type, and extent of the wear damage sustained or accumulated. Damage might include evidence of wear marks, indentation or fretting marks, buildup of metal debris and powder, metal cracking, or evident or incipient structural deformations. These examination techniques were to be further supported by an x-ray survey, by microscope inspection and dimensional check, and by profile machine measurements capable of measuring holes, pivots, and gear out-of-roundness to 0.00001-in. accuracy. The x-ray survey (not performed) was intended to assess subsurface damage or incipient cracking. The microscopic magnification of the small internal components by a factor of 50 or 100 facilitates the establishment of mechanical wear trends on complex configuration surfaces which are in intimate contact and constantly rub against each other; i.e., pivots and holes, meshing gears (pinion gear and rotor assembly), detent rotor and pivot, support plates, etc. A detailed drawing shows component composition of the S&A module (fig. 1). A cutaway drawing (fig. 2) shows the position of the S&A module within the fuze. Precision dimensional measurements are made in the HDL Mechanical Inspection Facility. The facility's equipment and capabilities are described in appendix B.

5.1.3 Chemical Analysis

To further quantify the baseline wear damage, the total metal powder debris was to be separated or extracted from the S&A module at the conclusion of the vibration test. Although internal components are constrained by the top and bottom plates (fig. 1), they are free to move somewhat during the test and to impact against each other and against the retaining plates (multiple collisions per cycle are quite likely). The impacts, friction, and rubbing effects involving components made out of aluminum, zinc, and hardened steel alloys produce metal debris that is picked up by the nearby assembly lubricants or is trapped by constrictions, indentations, cutouts, etc., of the module case. Although light in weight, (i.e., a few milligrams) the quantification of metal debris determined by involved chemical/mechanical techniques yields numerical results that are helpful in characterizing the accumulated wear damage. Because of funding constraints, qualitative analysis to determine material composition of the metal debris was not performed.

5.2 Computer-Controlled Shaker System

HDL's environmental test laboratory features a modern, up-to-date, computer-controlled electrodynamic shaker system that was used for these vibration tests. The equipment and software also enable design of a variety of complex, service-experienced environments to be synthesized efficiently and reliably. The computer control unit is shown in figure 6.

5.2.1 System Description

A simplified block diagram of the system is given in figure 7 (p 20). Use of digital minicomputers has enabled close coupling of sophisticated control drive techniques to dynamic (real-time) testing response. For the drives used in these tests (swept sinusoidal and random), control and monitoring of the shaker is relatively straightforward. A more complete description of the HDL system used for Transient Waveform Control testing was published in the 4th quarter, 1978 issue of the U.S. Army ManTech Journal.

5.2.2 System Operation

All test requirements are programmed on a coded test tape. The tape is obtained at the completion of a question and answer routine during which the operator is cued for test information by the test system controller. The coded tape, together with the transducer output data, provides a permanent record of the prescribed drive signal. At the completion of the test, the system prints out, on command, complete alphanumeric documentation of all test parameters as executed.

5.3 Transducers

Although the S&A module is vibrated over the 5- to 500-Hz range when subjected to the MIL-STD test, most of the wear damage probably occurs within narrow frequency sub-bands where the most severe component-to-case and component-to-component collisions and fretting occur. The parts that make up the S&A module itself could not be instrumented directly because of limited space and small component size. Thus, external sensors (macroscopic phenomena detectors) were used. These included an accelerometer and strain gage installed on the top (forward-facing) mounting plate of the S&A module and an acoustic transducer located at the inlet to the mounting sleeve, which simulated fuze housing and installation conditions. The sensors and their mounting method were selected so as to have a negligible effect on the dynamic response of the parameter being measured.

The purpose of this test was to measure the magnitude of vibration frequency activity as a function of the input test frequency and to establish from these data the frequency sub-bands for which vibration activity was dominant. Three types of

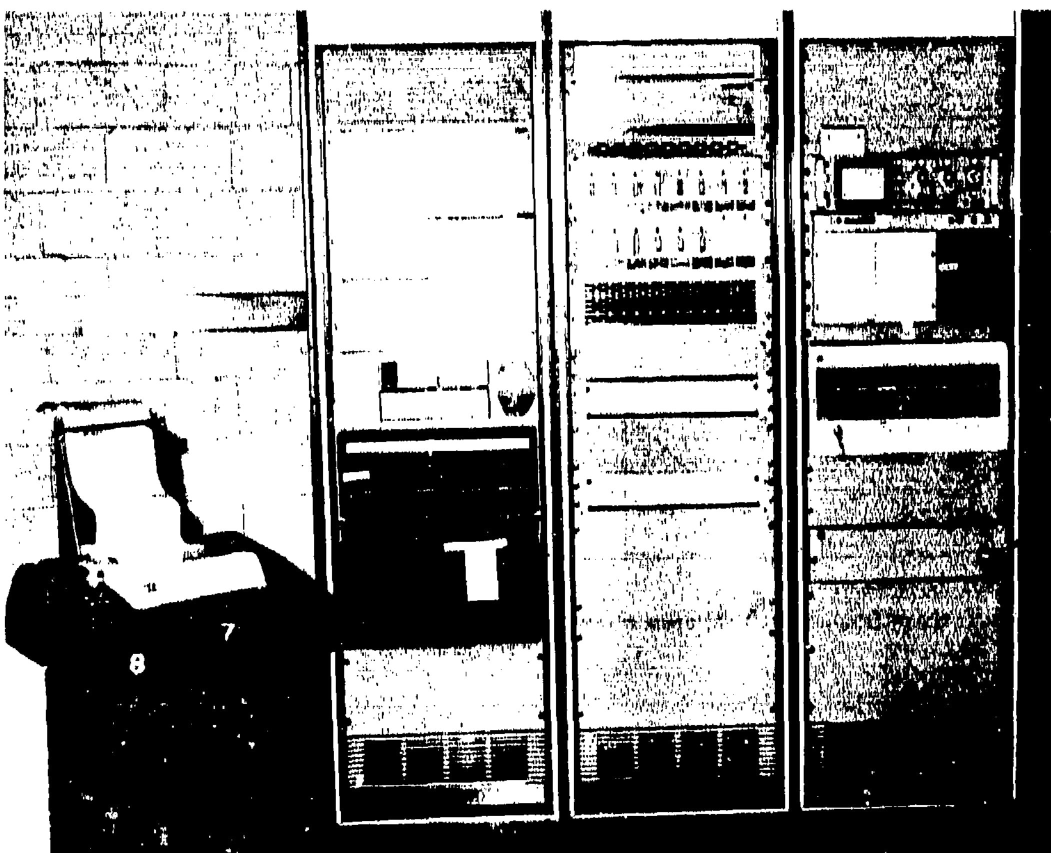


Figure 6. HDL Computer Control for Vibration/Shock Test System. (1) Digital minicomputer controller, (2) Minicomputer to generate vibration/shock transients, (3) X-Y plotter (amplifier versus frequency), (4) Display scope, (5) Precision gain amplifiers, (6) Paper-tape reader, (7) Teletypewriter Terminal, and (8) Paper-tape reader/punch.

sensors (acceleration, strain, acoustical) were used to provide separate and independent observations of test parameters; the multiple sensors also provided backup measurements in the event of loss or insensitivity of any one sensor's test data.

Test Sensors — Description and Use

A triaxial accelerometer, strain gages, and a unidirectional microphone were used to collect data for the tests described above. The position, orientation, and identification of each sensor during the test are presented. Also included — as appendix C — are the specifications for the accelerometer and for the strain gage.

Triaxial Micro-Miniature Accelerometer. — The sensor equipment industry was surveyed extensively to find a suitable miniature triaxial sensor for the specified applications. The device selected (Endevco Model 23) (appendix C-1) was

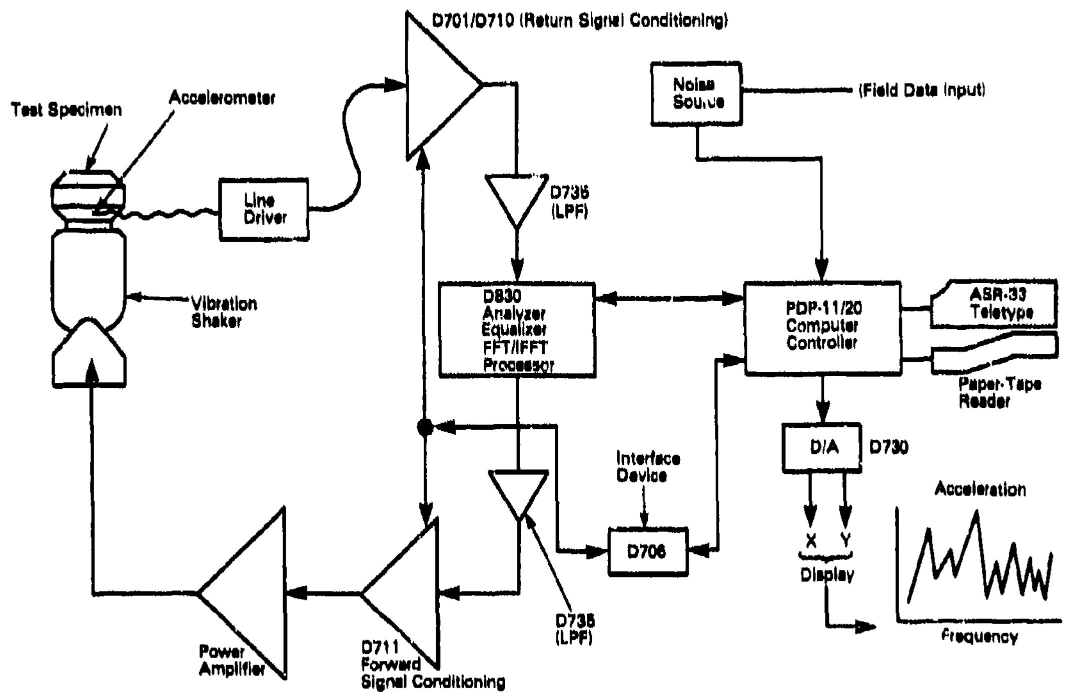


Figure 7. Harry Diamond Laboratories vibration/shock computer-controlled test system.

used as the primary indicator of vibration activity, providing simultaneous three-dimensional data as a function of the applied unidirectional input frequency/amplitude spectrum. The sensor's high-frequency sensitivity (frequency response, 10,000 Hz) enabled collection of reliable high-frequency vibration data, indicative of the high rate of component impacts. The transducer's low weight (140 mg) made it ideal for this application, where it is necessary to have minimum loading on the specimen being monitored. The sensor was initially mounted with special epoxy on the top cover plate of the first S&A module. After three tests were completed in run one, the accelerometer was removed from unit F-25, displaced 90 deg, and then epoxied back onto the cover plate. No tests were made on unit number F-24. The mounting position of the transducer is shown in figures 8 through 10. Figure 11 is a block circuit diagram indicating equipment setup and use.

Strain Gages (Entran Devices Model ESU-205-500). — Each of the two S&A modules were permanently instrumented with temperature-compensating (solid-state) strain-gage devices of the bridge type. The strain gages were placed in the radial and tangential directions with respect to the center of the S&A top cover plate (fig. 8 to 11). (No axial strain monitoring was possible.) The strain gages were used to (1) confirm and correlate vibration activity independent of the acceleration transducer, (2) demonstrate that the dynamic behavior of the S&A's top cover plate had not been altered substantially as a result of the installation of the micro-miniature transducer, and (3) serve as a backup sensor for the primary measurement (acceleration transducer). A major advantage of these extremely low weight solid-state strain gages is their negligible contribution to the observed values of the dynamic data. The block diagram (fig. 12) shows the strain gage circuit and its associated equipment.

High-Accuracy Unidirectional Microphone (Gen Rad Model 1560-P42). — This acoustical sensor was selected as another backup and validation measurement for the previously described sensors. One major difference in its application from the others is that it involved no physical contact with the test specimen, thereby providing absolute dynamic isolation. It was installed in a fuze sleeve 1/4-in. above the top cover plate of the S&A module (fig. 13(a)). Precautions were taken and measurements were made to ensure that its mounting within the open-ended port of the sleeve produced no significant standing waves. Effective use of this sensor required suppression of background noise (by at least 20 dB). This attenuation was possible with HDL's small (50 lbf) calibration shaker, but the condition was not met when the heavy-duty shakers were used during the baseline test on the instrumented modules. For the latter case, the background noise severely masked the acoustic test data, and those measurements could not be used. Figure 13(b) shows the S&A compartment filled with duxseal, an acoustically inert material that was used to determine a reference noise level for the system.

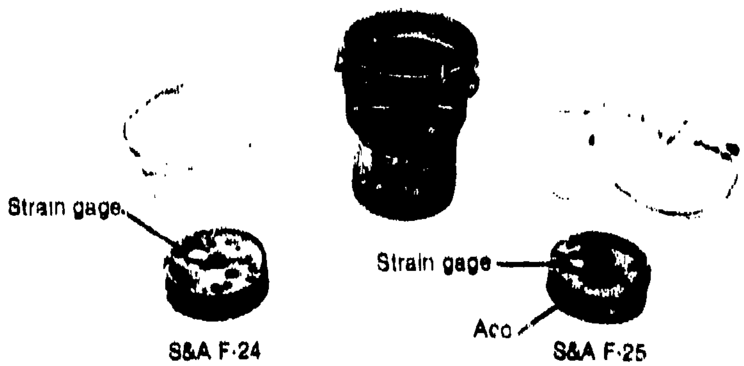
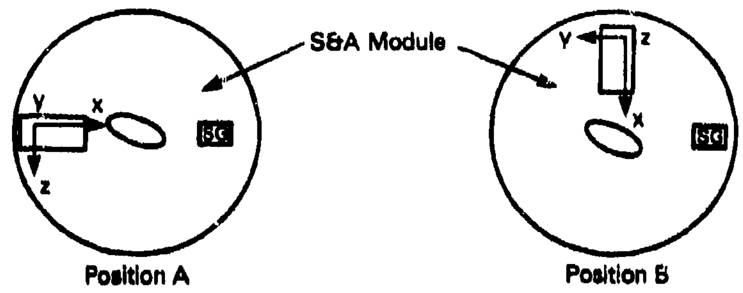
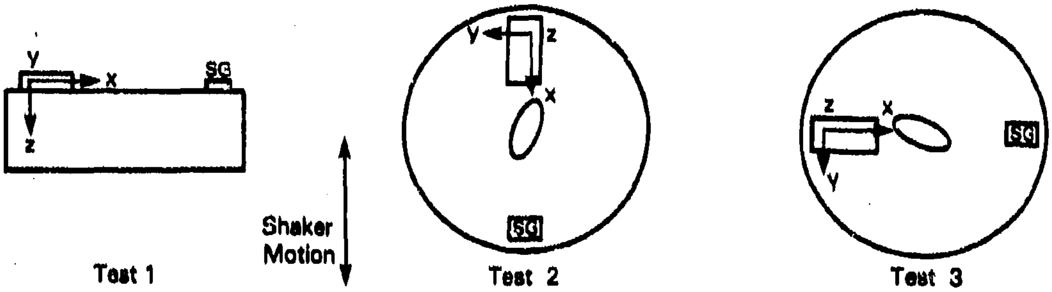


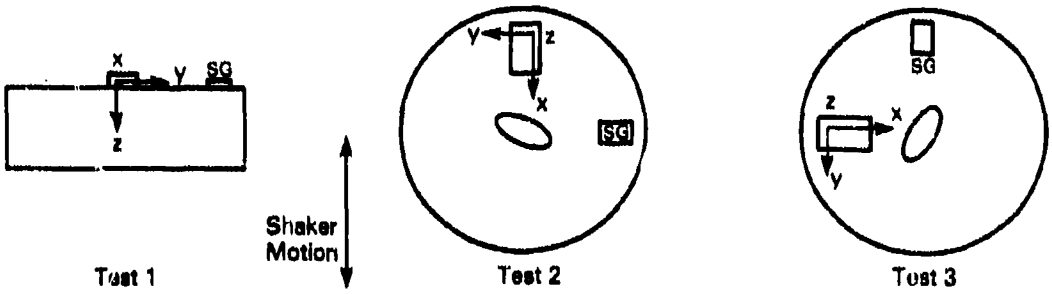
Figure 8. M732 fuse housing, S&A modules with tri-axial accelerometer and strain gage affixed.



(a) Accelerometer & strain gage (SG) mounting positions.

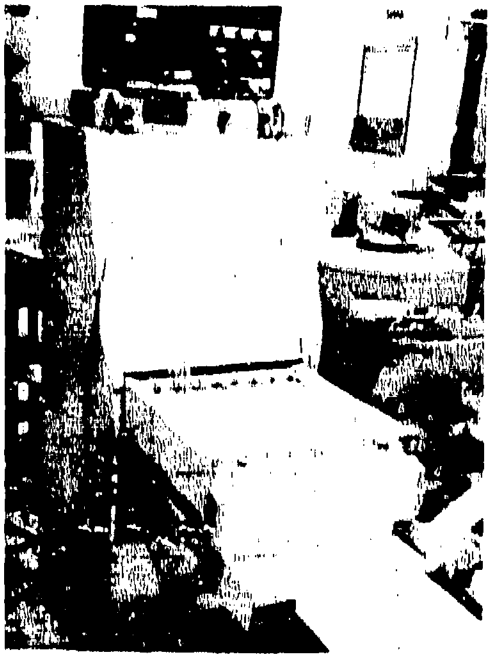


(b) Mounting positions of S&A module for run number 1.

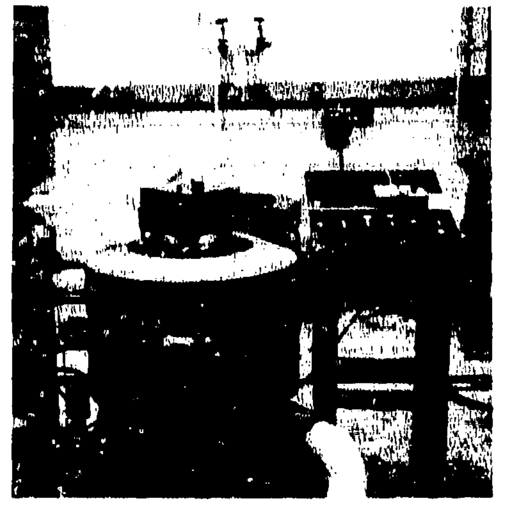


(c) Mounting positions of S&A module for run number 2.

Figure 9. Mounting positions of accelerometer and strain gage on top plate of S&A modules; also, mounting positions of S&A module on shaker test fixture for transportation vibration test runs.



(a) Gould chart recorder (foreground); shaker is seen at right center.



(b) Front view of test equipment; shock amplifiers are to right of shaker.

(c) Overhead view of S&A in fuze sleeve; also shown are fixture and shaker.

Figure 10. Test setups for MIL-STD 331 transportation vibration tests.

5.4 Sinusoidal (Baseline) Measurements

Sinusoidal vibration measurements were made on one fully instrumented S&A module (S/N F-24), to establish the frequency sub-bands within the 5- to 500-Hz range for which the vibration activity is dominant. Each sensor — including its test channel and the analog/FM tape and chart-recorder system — was calibrated before and after each test.

5.4.1 Data Records

This section describes the tests, measurement procedures, data tape identification, and equipment sensitivity for a transportation vibration test sequence.

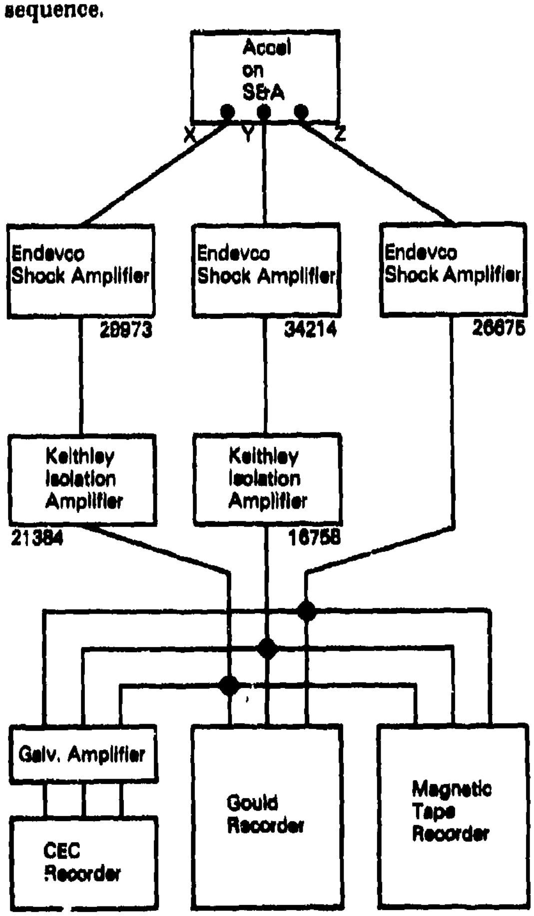


Figure 11. S&A device test; tri-axial accelerometer circuit.

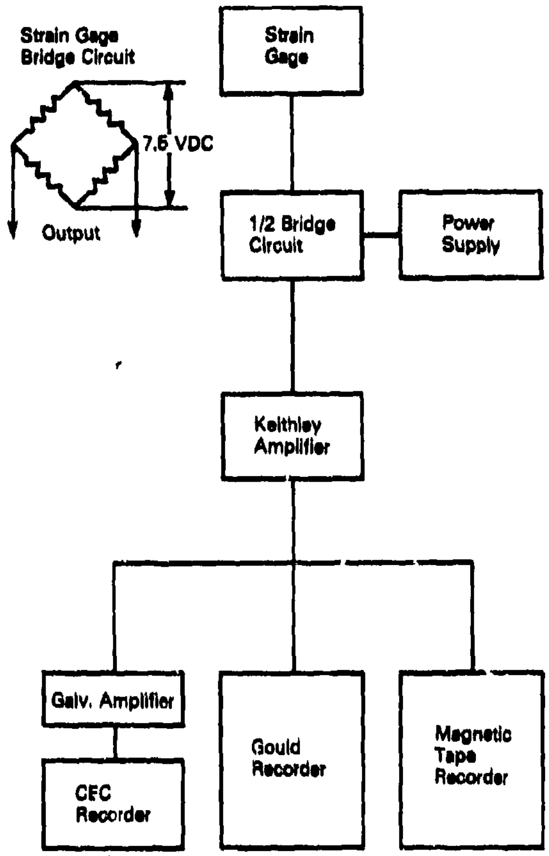


Figure 12. S&A device test; strain gage circuit.

Test Description. — A typical vibration test cycle consists of the following sinusoidal (input) sweep envelope (fig. 4).

Amplitude	*Frequency*
0.4 in., p-p	5 to 11
2.5 g, O-p	11 to 37
0.036 in., p-p	37 to 52
5.0 g, O-p	52 to 500

The standard TV test cycle takes 1 hour; for this baseline test, a test consisted of one half-cycle, having a 30-minute duration. Each unit was run three times with the fuze (S&A) orientation aligned once in each of three mutually perpendicular directions (fig. 9), for a total run time of 90

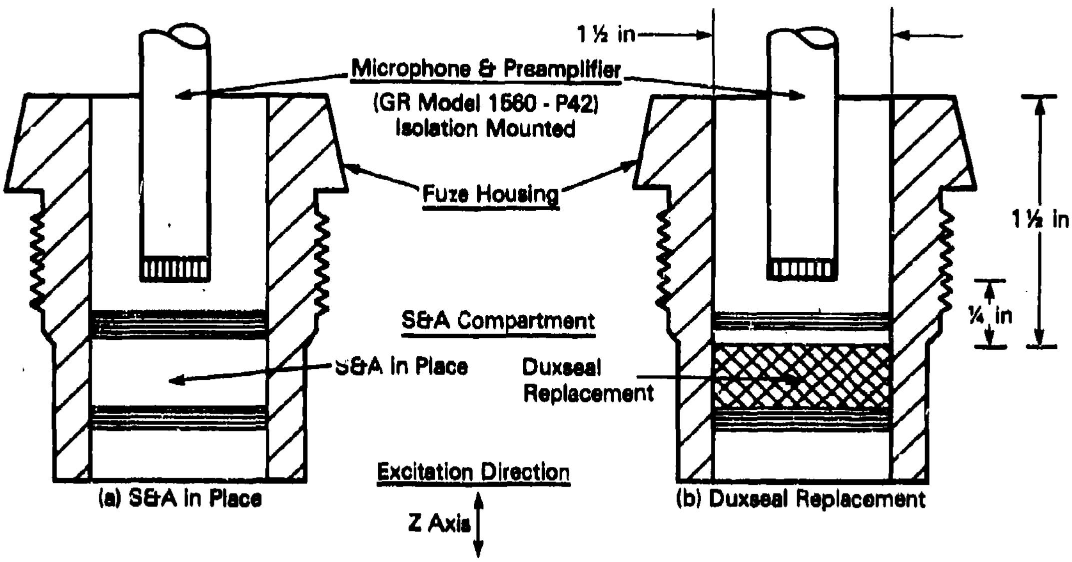


Figure 13. Acoustical test setup showing microphone mounting.

minutes. The transducer position was then relocated by shifting 90 deg and repeating a second run of 90 minutes as before.

Measurement Description. — Six measurements plus one IRIG-B time code were recorded for each test. Total records required three data tapes with two tests recorded on each tape. Tape channel identification is as follows in table 3.

TABLE 3. TAPE CHANNEL IDENTIFICATION

Measurement		Channel Number
Triaxial accelerometer	X	6
	Y	5
	Z	4
Strain gage		7
Control accelerometer (input)		3
Control frequency (input)		2
IRIG-B		1
Voice edge track		8 (1 pulse/s)

Data Tape Identification. — Three 1-in./FM analog data tapes were recorded at a speed of 7.5 in./s. Each channel was calibrated at the beginning of each tape; in some cases, pre- or post-test calibration was also performed. Tape 1 contains data for transducer position 1, runs 1 and 2; tape 2 contains data for position 1, run 3, and transducer position 2, run 1; tape 3 contains data for position 2, runs 2 and 3.

Equipment Sensitivity. — The equipment sensitivity is noted as follows.

X axis	13.3 mV/g_{pk}
Y axis	13.7 mV/g_{pk}
Z axis	14.6 mV/g_{pk}
SG	1.9757 mV/μstrain
Control acceleration	10.0 mV/g_{pk}
Control frequency	2 mV/Hz

5.4.2 Data Reduction

Data reduction involved spectral analysis of four measurements (X, Y, Z, & SG, table 3) for each of the six tests (fig. 9) as follows.

(a) An amplitude plot (voltage or strain for SG; g for acceleration) vers·· frequency in the 5- to 500-Hz range to ascei ·he regions where the response amplitude and mechanical collisions are most intense.

(b) Spectral analysis for the axial (input) direction to include relative response amplitude and relative frequency plots versus input frequency; this is accomplished by extracting the content of the input control acceleration and frequency signal from the axial response measurement and plotting the results against input frequency.

(c) Power spectral density (PSD) analysis yielding g^2/Hz versus input frequency (in Hz) for all response and control measurements (excluding input frequency) for all tests.

This analysis was performed with commercially available special-purpose computer codes.

5.5 *Spectral Analysis*

5.5.1 *Description and Method of Analysis*

Spectral analysis of time-domain test data (described in sect. 5.4) consists of data transformation from the time domain to the frequency domain to yield response amplitude versus excitation frequency information. This is normally accomplished by special-purpose computer codes programmed to handle digitized data blocks (frames) of finite length (typically 1024 words/block), the sum of which represents the complete analog record (test data) under evaluation. Spectral analysis thus provides a simplified means of evaluating the composition of complex/random test data by transformation into a meaningful x-y representation of magnitude versus frequency. Spectral analysis was applied to this task to identify the frequency sub-bands, or spectral range, for which mechanical wear damage, as reflected by large response amplitudes, was most pronounced. Two types of spectral analysis were used: a PSD analysis and a response amplitude analysis. The PSD was computed as follows.

$$\mathrm{PSD}[X(f)] = \frac{(\mathrm{FFT}[x(\Delta T,F)])^2}{\Delta f} \quad (g^2/\mathrm{Hz}) ,$$

where

$x(\Delta T,F)$ = 1024 point data block

ΔT = data time increment,

F = excitation frequency,

Δf = data resolution bandwidth with $\Delta f = 8$ Hz,

f = response frequency,

FFT = Fast Fourier transform algorithm, and

X = Fourier representation of x.

The response amplitude $g(F_i)$ was computed from the accelerometer and strain-gage PSD records $(F_i, \Delta T_i)$ as follows, where ΔT_i is a 2-s increment within the total 30-min data record, F_i is the corresponding drive frequency at the start of the increment, and ΔF = 495 Hz.

$$g(F_i) = \left[\Delta F \cdot \mathrm{PSD}(F_i, \Delta T_i)\right] \quad \mathrm{rms} .$$

Equivalently, $g(F_i)$, the amplitude at the i^{th} drive frequency, is equal to the square root of the area under the PSD curve for that particular time increment.

5.5.2 *Analysis Parameters and Procedures*

The spectral analysis parameters and procedures are described as follows.

(a) Sampling frequency: 8 kHz with anti-aliasing filters set at 1 kHz.

(b) Analysis bandwidth: 5 to 500 Hz, occasionally expanded to 1 kHz.

(c) Data frames (blocks): 2 s long; 1024 points, taken over the entire length of the data record (900 frames total).

(d) Average $\mathrm{PSD}(x) = \dfrac{\sum_{i=1}^{N} \mathrm{PSD}(x_i)}{N}$,

$N = 900$.

(e) Engineering units: PSD — g^2/Hz.

(f) PSD display: g^2/Hz versus frequency (Hz).

(g) Response amplitude: The rms value of the accelerometer or strain-gage measurements as functions of the sweep frequency is obtained from the previously derived PSD. Each of the 900 records is stored in a separate data file; this bank is used to construct the amplitude versus frequency curve. The drive frequency was monitored by a channel calibrated against a proportional dc reference voltage. The PSD of each transducer channel output was computed for each 2-s interval over the 5- to 500-Hz range and converted to g rms at the specific frequency corresponding to the instantaneous test time. The derived response amplitude thus represents a composite value of all PSD data records at the specific excitation frequency.

(h) Engineering units: All response amplitude versus frequency plots are presented in units of acceleration versus frequency for the accelerometer measurements (x,y,z, and control input*); the response amplitude for the strain-gage measurement is presented in terms of rms strain voltage versus frequency.

6. TEST RESULTS

6.1 Transportation Vibration Test Log

S&A modules, serial numbers F-1 through F-23 and F-26 through F-29, were subjected to either the standard TV test or to random vibration testing. This exposure history is presented in table 4.

Groups 1 and 2 (units F-1 through F-8 and F-9 through F-16, respectively) were used as baseline controls. Group 3 was used in the first RTV test to ascertain preliminary damage equivalency and to effect fine modifications (adjustments) to the test procedure. Group 3 was run at 5 g, group 4 at 10 g, group 5 at 15 g, and group 6 at 20 g. The various g levels were employed to determine the correlation of g level and wear damage. The information was also to be used to ascertain or trade off test amplitude and test duration, since an increase in amplitude intensity can be offset by a decrease in test time (though not linearly) for similar damage levels.

*The control input channel data were not printed out for this analysis.

6.2 Visual Examination of Vibration-Tested S&A Modules

Post-test examination and reports on the baseline and random-vibration tested S&A modules were made and prepared by HDL engineers associated with the development and production of this fuze component. The test data on TTA are given in table 4. The following paragraphs are from the engineers' observations and analysis.

6.2.1 Test Group 1 (Baseline TV Test)

The following paragraphs describe the TTA test methods and the damage found when the units were inspected after testing.

TTA Tests. — S&A modules (PN11716741) of serial numbers F-1 through F-8 were tested initially for TTA and (except for F-4) were subjected to a MIL-STD-331 TV test, Method 119, Procedure I (4 hr per axis at ambient temperature). They were then retested for TTA with the results shown in table 4. One of the units (F-6) was the slowest of the seven to arm initially and barely ran after the vibration test. No numerical value for TTA was obtained for this unit on the rerun. If only the six units which ran both times are considered, the average TTA increased from 28.8 to 29.9, with only one of the six units running faster (0.5 turn) after vibration.

Visual Examination. — After the TTA was determined, the units were disassembled and examined under a microscope for visually observable damage. The units that ran slower after vibration displayed a more noticeable buildup of fretting corrosion products around the pivot journals. It consisted of a black-colored deposit, embedded with aluminum particles. The deposit looked "thick," "dry," and "crusty," and some of it had broken up and scattered throughout the unit. On units F-1, -2, and -6, the deposit at the lower rotor

TABLE 4. SPIN TESTS — M732 S&A MODULE (GENERAL TIME, INC./LOT WTX-2-2) PN11716741

Unit No.	Group	TTA-B (before)	TTA-A (after)	Change	Remarks
Baseline Sinusoidal test					
F-1	1	28.9	29.2	+0.3	Group 1 tested April 1976.
F-2	1	29.0	29.8	+0.8	
F-3	1	29.5	29.0	−0.5	
F-4	1	30.1[a]	—	—	Not vibrated.
F-5	1	29.8	30.6	+0.8	
F-6	1	31.4[a]high	(b)	(b)	
F-7	1	26.4 (low)	28.2	+1.8	
F-8	1	29.5	32.8	+3.3	
Average	—	28.8	29.9	+1.1	
F-9	2	27.2	—	—	Group 2 tested June 1976.
F-10	2	30.8 (high)	—	—	Remarks: TTA-A for units of
F-11	2	27.8	>300	—	this group having dash, tested
F-12	2	29.2	—	—	between 50 and 150 turns.
F-13	2	26.3	—	—	
F-14	2	26.1 (low)	30-25	—	
F-15	2	27.6	—	—	
F-16	2	28.8	—	—	
Average	—	28.0	—	—	
Random TV test (5 g rms)					
F-18	3	28.0	28.5	+0.5	Group 3 tested October 1976.
F-19	3	26.3	29.2	+2.9	
F-20	3	29.1	29.8	+0.7	
Average	—	27.8	29.2	+1.4	
Random TV test (10 g rms)					
F-21	4	26.3	26.6	+0.3	Group 4 tested October 1976.
F-22	4	26.5	27.9	+1.4	
F-23	4	30.1[a]	(b)		
Average	—	26.4	27.3	+0.8	
F-24	—	26.5	—	—	Used for analysis of maximum
F-25	—	28.7	—	—	damage sub-bands within standard TV test.
Random TV test (15 g rms)					
F-26	5	26.3	34.4	+8.1	Group 5 tested October 1976.
F-27	5	28.1	30.2	+2.1	
F-30	5	30.1	32.2	+2.1	
Average	—	28.2	32.3	+4.1	
Random TV test (20 g rms)					
F-28	6	32.0	(b)	—	Group 6 tested October 1976.
F-29	6	29.5	32.2	+2.7	
F-17	6	27.5	34.4	+6.9	
Average	—	28.5	33.3	+4.8	

[a] *Not included in average.*

[b] *No value obtained.*

pivot was "oily," whereas it appeared almost dry on the other four units. Unit F-1 was especially oily.

Considerable indentation was evident in the top and bottom plates, attributed to impact of the pivot shoulders on all four "dry unit" mobile assemblies. There was also noticeable scarring of the underside of the top plate caused by the spin locks, rotor detent, and detonator. Observation of the vibration damage was classified qualitatively as "heavy." The most wear occurred around the rotor pivots and in the area where the detonator hits the top plate. All pivots of the mobile assemblies exhibited increased clearance due to vibration wear. In addition, nothing was seen that would explain the failure of unit F-6 to arm within specification.

The units were reassembled and placed in individual plastic bags. The top plates were "snapped" back onto the studs, but they could easily be pried off.

6.2.2 Test Group 2

The following paragraphs describe the TTA test methods and the damage found when the units were inspected after testing.

TTA Tests. — S&A modules of serial numbers F-8 through F-16 were tested initially for TTA and were then subjected to the TV test. They were then retested for TTA, with results as follows. None of the units ran within specification (25 to 38 turns) after the vibration test. All the units armed eventually, but the TTA was not obtained since the spinner stop signal did not stop the counter. A rerun of the units for numerical values showed that units armed in the region of 50 to 150 turns, except for unit F-11, which took more than 300 turns and unit F-14, which took between 30 and 35 turns. Unit F-14 had been the fastest of the group of eight units before vibration, with a TTA value of 26.1. Post-test results as indicated by TTA differed drastically from those obtained for the first group of seven vibrated units, in which six of the seven units armed within specifications after vibration testing, slowing down by an average of only 1.1 turn. This was exceptionally perplexing since all units came from the same lot, and the TV test procedure was exactly the same as that performed on the Group 1 units. This problem is discussed in more detail in section 7.2.1.

Visual Inspection. — After the TTA tests, the units were disassembled and examined for vibration damage under a microscope. These units also showed a severe buildup of the black-colored fretting corrosion deposits embedded with aluminum particles. These deposits appeared noticeably heavier than those observed in units of the first group. The deposits looked very dry — drier than Test Group 1. In addition, most of the deposits appeared to have broken away from the contact interfaces, and they had scattered throughout the units. Only unit F-10 gave the slightest visual appearance of oil in some of its deposits; moreover, there seemed to be more deposits on this unit than on the others. In general, the pivot shoulder, journal damage to the plates, and wear of the gear meshes looked about the same on these units as they did on units of the first group. However, deformation of the spin locks and the rotor detent, scuffing of the rotor by the shutter, and scuffing of the underside of the top plate by the detonator, appeared to be more severe than that observed on the units of Test Group 1.

Nothing specific was observed that would cause unit F-14 to run appreciably faster than unit F-11. However, the longer arming time for units of Test Group 2 could be attributed to the general lack of visible oil lubricant and the larger amount of fretting corrosion products.

Mechanical Inspection. — The visual observations that were made on damage to post-test parts indicated those component locations and dimensions (bearing surfaces, holes, etc.) that should be measured physically to obtain quantitative data. In the final analysis, a decision as to "equivalency" in test methods will be best satisfied by precise dimensional comparative measurements.

It was assumed at first that the dimensions, as specified by the SCD, would be used as the basis for later reference. In large part, this was a forced approach, since it was difficult to specify exactly what would wear (thus, what should be measured). In addition, routine scheduling of tests would also have delayed start of the vibration tests. However, it had been learned from many years of experience, that part dimensions can exceed SCD tolerances and thus cannot be relied upon without verification, especially not for the types of data sought by this project.

Nevertheless, measurements were made after the vibration tests on several parts to evaluate results and to familiarize the HDL inspectors with the types of measurements that would be required. Several parts were viewed optically at magnifications of 30-, 50-, and 100 X. No surface defects were noted other than wear. The profilometer (for specifications see appendix B) was used to obtain data on a plate cover hole, a housing hole, housing pin, and rotor pin (both gear side and far gear side). Charts of the plate cover hole and housing pin runout are shown as figures 14 and 15. For the unit tested, data were within SCD tolerances.

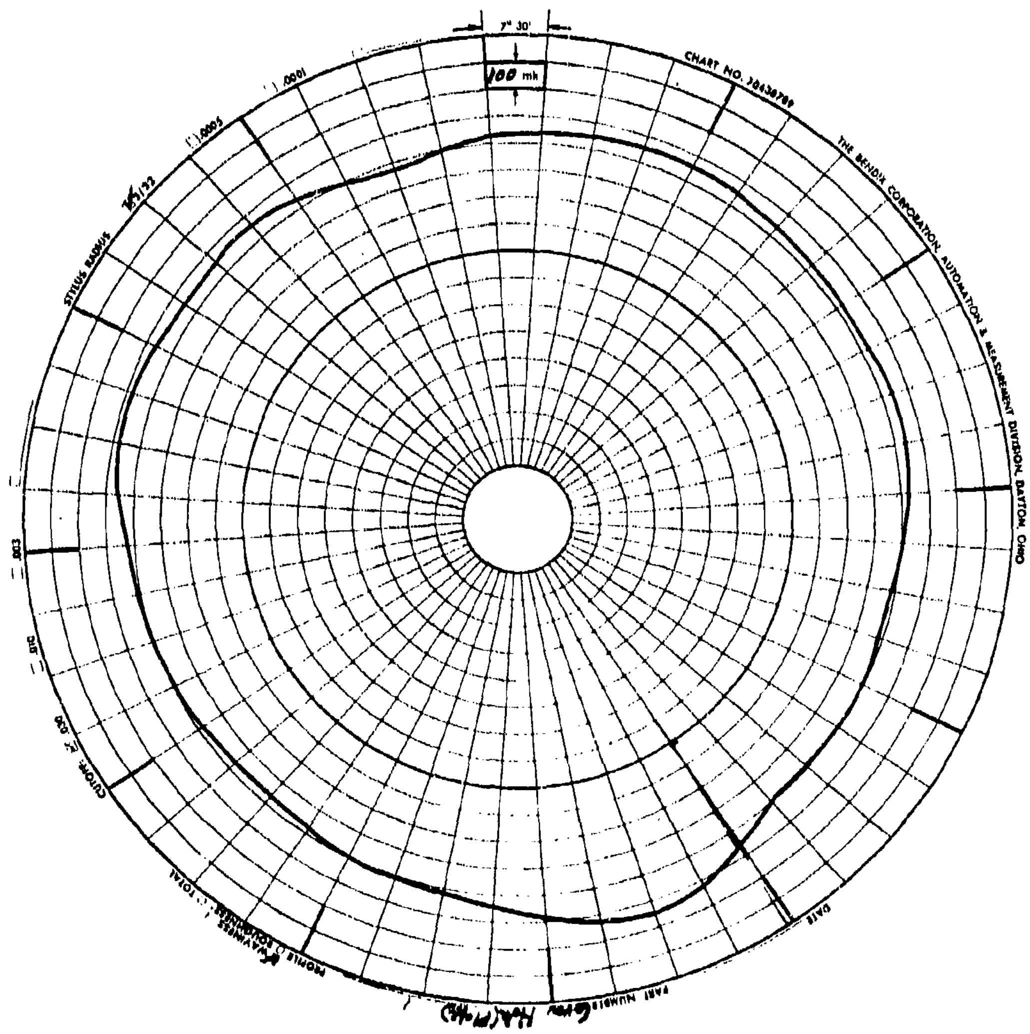


Figure 14. Profilometer runout chart—cover hole(plate).

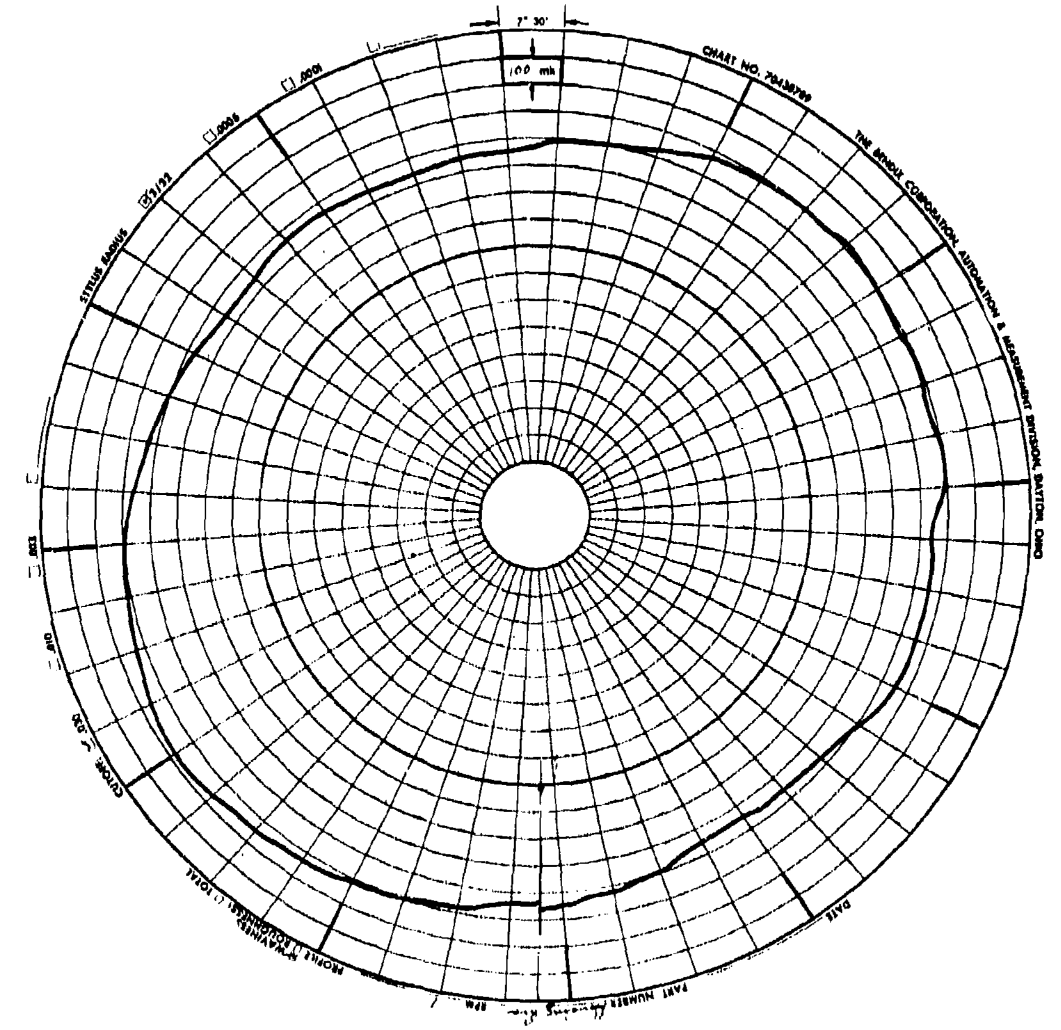


Figure 15. Profilometer runout chart—housing pin.

6.2.3 Test Group 3 (RTV Test)

The following paragraphs describe the RTV Test Methods and the damage found when the units were inspected after testing.

Test Description. — Twelve S&A modules were subjected to the RTV test (20 min per axis); they were tested for TTA both before and after the vibration test, with results as shown in table 4. Column TTA-B indicates operational results on units before the random vibration tests; column TTA-A, after the tests. Note that the increased levels of vibration tended to result in increased TTA (except for Test Group 4, not discussed, but listed in table 4). Note also that for some g levels, damage comparable to that incurred in 12 hours of standard TV testing was made to occur in just 1 hour of RTV testing.

Visual Inspection. — After post-test TTA measurement, units were disassembled and examined with a microscope for vibration damage.

There was little damage on units vibrated at 5 g and only a small amount of fretting corrosion products. Damage occurred only at the pivots and at the junction where the detonator meets the top plate. There was more extensive damage to the units vibrated at 10 g. The spin locks and rotor detent had started to abrade the top plate. There were also thicker black fretting deposits and considerably more observable aluminum particles. Units vibrated at 15 g exhibited only slightly more damage and fretting than did the 10-g units. Abrasion was also noticed in this group on the bottom plate contact area where the large pivot shoulders bear. All units in this group had evidence of ample oil lubrication and it is believed that this oil could have conferred some resistance to fretting corrosion. The group vibrated at 20 g had only slightly more wear damage and fretting products than did units of the 15-g group. There was evidence of ample oil in this group also. The increase in damage between the 10- and 20-g group was about as much as the increase seen between the 5- and 10-g group, so that the amount of damage versus g appeared to be leveling off. The damage observed on this group of 12 units appeared to be much less than on the 7 units of Test Group 2. The most seriously damaged unit of these groups may be comparable in extent to that of the seven units tested in Group 1, but this is a qualitative estimate at best. Most of the observations for Group 1 made in paragraphs two and three referring to the baseline units also apply to observations in units run in this series of tests. Results indicate that a longer test time would be necessary at the 10-g level (to match sinusoidal TV damage) or a shorter test time would be required at the 15-g level (to reduce TTA to the sinusoidal TV test results).

6.3 *Acoustical Test Data*

Figures 16 through 18 are copies of test data records obtained with the acoustic sensor during the standard prescribed sinusoidal sweep test covering 5 to 500 Hz. The physical test setup is shown in figure 13. When the S&A was in the sleeve (fig. 13(a)), high-level vibration activity was observed in the 150- to 250-Hz range (phone channel, chart record, fig. 14). When the S&A

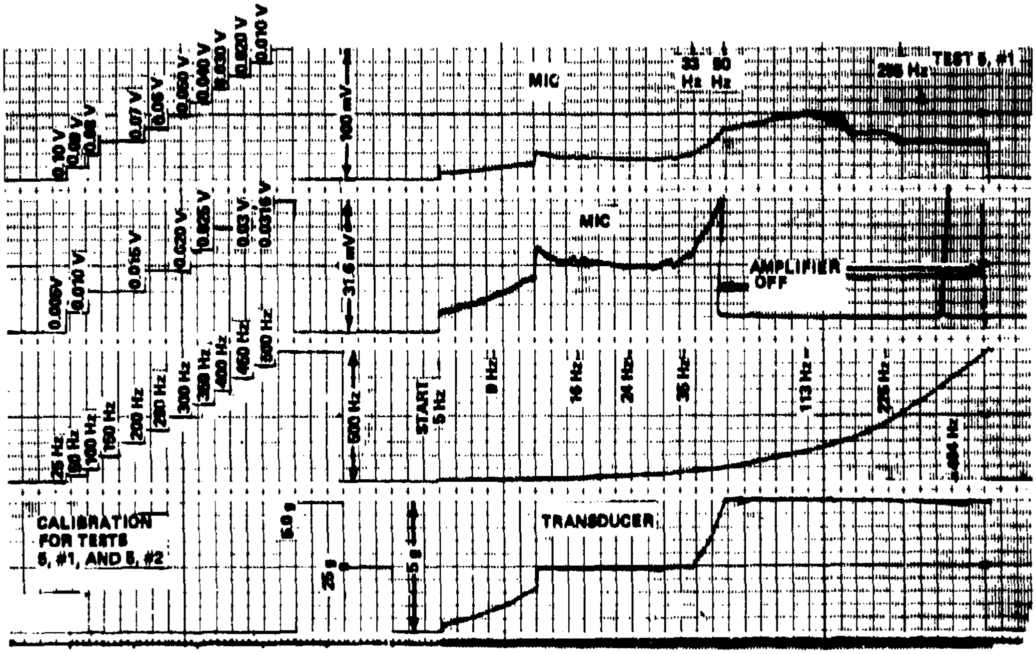


Figure 16. Microphone chart record—calibration and response to MIL-STD 331, Method 119 test with S&A in place.

module was removed from the test sleeve and replaced by duxseal (fig. 13(b)), the same phone channel indicated very low response in this same range as can be seen in figure 15. The high response activity region is marked by high-frequency components; this can be interpreted physically as being due to the increased level of component collisions ("bounce"). The existence of multiple impacts for particular frequency sub-band drives is more apparent when selected oscilloscope records of the microphone channel are viewed at 61, 108, and 225 Hz. The oscillograms of figures 18a, b, and c display results at 5-g drives for each of the above three frequencies. Records are for the S&A in place (left side) and again with the S&A removed and replaced by a duxseal compound (right side). The duxseal unit provides bulk equivalency and serves as a reference background noise level for the system. Considerable activity is observed when the S&A is in the sleeve; the response function is altered considerably as a result of the superposition of high-frequency components generated by multiple collisions, or rebounds, of components against the top and bottom cover plates of the S&A module or between the components and subassemblies themselves. These results were expected. Although the preceding records were obtained for vibration along the axial direction, data for vibratory drive in the radial directions (test positions 2 and 3 of fig. 9) would exhibit similar trends, with the exception that the most damaging vibration frequencies might shift to

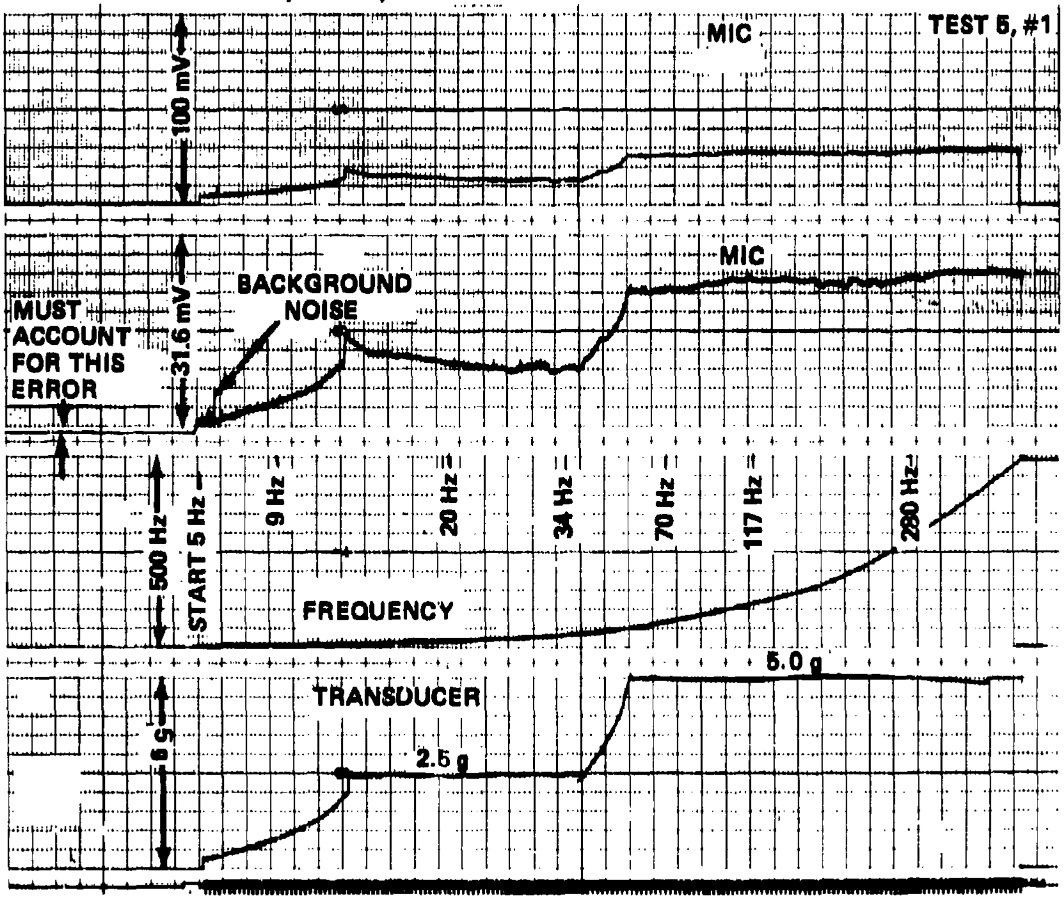
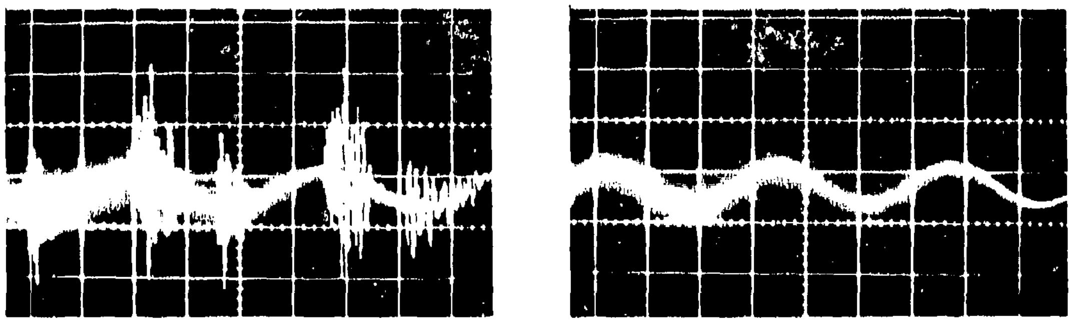
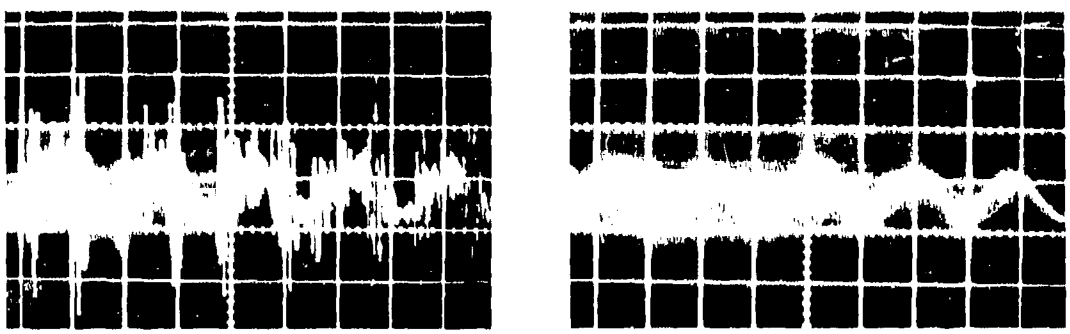


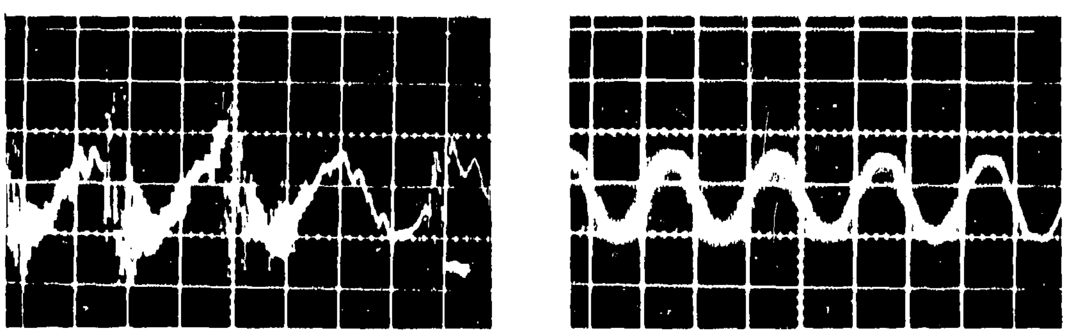
Figure 17. Microphone chart record—response to MIL-STD 331, Method 119 test with duxseal replacement for S&A.



(a) 61 Hz



(b) 108 Hz



(c) 225 Hz

Figure 18. Oscillogram records — acoustical data at discrete drive frequencies.

other bands within the 5- to 500-Hz range in response to the different component orientation and associated stiffness.

6.4 Chemical/Mechanical S&A Module Metal Debris Collection

Chemical/mechanical separation techniques were developed and used in an attempt to quantify the wear damage resulting from baseline and random vibration testing. Informative memoranda regarding this task are given in appendix D. They will be referred to in the discussion, section 7.2.2 and 7.3.

It was initially thought that metal debris generated as a result of component intercollisions and fretting actions could serve as a precise numerical index for the characterization of total wear.

The debris collection operations turned out to be very tedious, exacting, trial-and-error procedures that saw marked improvement as the process developed. This was understandable, since operations of this type had not been attempted previously at HDL and specific procedures had to be devised for this particular application.

Quantitative results from this task are presented in table 5. The total weight of the metal debris collected from each S&A unit (consisting primarily of aluminum, zinc, and steel alloys in the form of particles and fine powder) are listed in the column titled "total particles." Data for the first baseline

TABLE 5 TEST RESULTS: POST-TEST METAL DEBRIS ACCUMULATED IN M732 S&A MODULE

Test group	Run No.	Gross wgt loss	Coarse particles	Fine particles	Total particles	Gross total oil and lubricants	Remarks
1							
Baseline sinusoidal	F1 to F8	—	—	—	—	—	Lost (inconclusive results)
	F9	—	—	—	0076	—	
	F10	—	—	—	0096	—	—
	F11	0.0161	0.0065	0.0203	0065+	Uncertain	Fines on paper can't trust.
	F12	0.0159	0.0090	0.0008	0098	Uncertain	—
	F13	0.0162	—	—	0142	0020	—
							(g)
2	F14	0.0419	—	—	0.0059	—	—
Baseline sinusoidal	F15	0.0129	—	—	0.0082	0.0047	—
					Avg. 0.0090		
	F17	0.0113	0.0050	0.0009	0.0059	0.0054	20
	F18	0.0096	0.0037	0.0013	0.0050	0.0046	5
	F19	0.0063	0.0028	0.0005	0.0033	0.0030	5
	F20	0.0127	0.0033	0.0004	0.0037	0.0090	5
	F21	0.0115	0.0037	0.0004	0.0041	0.0174	10
3	F-22	0.0134	0.0027	0.0008	0.0035	0.0099	10
Initial equivalent random vibration test	F23	0.0067	0.0027	0.0011	0.0038	0.0029	10
	F26	0.0074	0.0022	0.0003	0.0025	0.0049	15
	F28	0.0099	0.0027	0.0005	0.0032	0.0067	20
	F29	0.0134	0.0030	0.0006	0.0036	0.0101	20
	F30	0.0098	0.0026	0.0005	0.0031	0.0067	15

test (Group 1) were inconclusive; an analysis procedure was being developed concurrently and the results that were obtained cannot be considered as accurate as the data measured on subsequent groups. The second baseline test (Group 2) averaged 8.83 mg of debris per module with significant variance around the mean. These values were substantially higher than expected. The higher than expected amount of debris is consistent with the massive functional failure noted during the post-vibration TTA test (see Group 2 results, sect. 6.2.2).

A review of the test results for the random vibration test (tables 5 and 6) indicates that although better process control existed for these analyses regarding debris separation repeatability, these modules (1) averaged approximately 50 percent less (~4.0 mg) total debris than was collected in the baseline test on Group 2 and (2) no wear correlation as indicated by total wear debris could be established as a function of increased rms level of excitations. Since finding (1) above cannot be accepted until more baseline tests are performed, no conclusive correlation can be made between the sinusoidal and random test regarding wear debris. The leveling off of accumulated debris at the increasingly higher random vibration excitation levels (15 and 20 g rms) was thought originally to represent an anomaly because of the small sample size (three units). However, confidence in the analysis method and its precision led to the conclusion that damage at the higher gravity levels had to occur as part distortion rather than part abrasion.

TABLE 6. SUMMARY OF POST-RANDOM VIBRATION TEST METAL DEBRIS COLLECTED FROM M732 S&A MODULES

Group No. 3	Random vibration test (g rms)	Average weight of debris for subgroup mg/module
18	5	4.0
19	5	
20	5	
21	10	3.8
22	10	
23	10	
26	15	2.8
27	15	
30	15	
17	20	4.23
28	20	
29	20	

One reason for weight variance within any sample group may be due to metal debris that is possibly lost during post-test disassembly and manual inspection of the module before the initiation of the chemical-mechanical separation procedure. This loss is practically unavoidable, but it is considered to be of relatively small magnitude compared to the total weight of the metal debris.

Table 7 summarizes data (see app D, table D-1) collected on S&A units "as delivered." Data were obtained in January 1978, after the chemical analysis technique had been perfected. It is presented in this section primarily to indicate the precision that can now be achieved with this method. It should be noted that the metal debris collected from each unit is nearly the same (0.0017 ± 0.0004 gms), whereas there is a more than 2:1 difference between the minimum and maximum amounts of oil collected. This is discussed further in section 7.2.2.

TABLE 7. SUMMARY OF DATA ON OIL AND METAL COLLECTED FROM LOT-DELIVERED M732 S&A MODULES (REFERENCE APPENDIX D, TABLE D-1)

Debris/oil	F38	F48	F58
	Unit No. (gms)		
Metal debris and oil collected by "washing"	0.0058	0.0019	0.0083
Large particles	0.0010	0.0015	0.0017
Fine particles	0.0003	0.0002	0.0003
Total particles	0.0013	0.0017	0.0020
Oil	0.0045	0.0102	0.0063

7. DISCUSSION

To a large extent, test results, observations, and conclusions must be considered tentative since (1) sample sizes were small, (2) some tests were being done for the first time, and (3) approaches were modified as information was acquired. An apparent contradiction exists because some data are precise and definite trends can be observed; yet, anomalous behavior was exhibited both by group and by units. Certainly, additional tests are called for with more definitive boundary conditions and fewer variables. As discussion will show, one variable requiring closer control is lubrication of the S&A.

7.1 Turns-to-Arm

TTA proved to be a quite reliable yardstick in determining the condition of the S&A. Generally, TTA before test appeared reasonably the same for all units (table 4). Unfortunately, TTA-B were all measured when delivered (after detonator replacement). Future tests should specify that TTA-B be performed just before vibration testing. Except for some anomalous behavior, and allowing for small sample size, TTA-A data were consistent with observed test condition severity (more damage, longer arming time) and specific types of damage.

7.2 Lubrication

7.2.1 Group 2 Results

Although TTA-B for Group 2 was consistent with data of other groups, TTA-A was marked by catastrophic failure. Since this group was subjected to the same test as Group 1, the results were totally unexpected. An explanation can be deduced only from post-test observations of the S&A and from previous experience of the S&A designers.

The S&A units were delivered prelubricated and sealed in plastic pouches. The detonator was replaced at HDL; the units were tested for TTA and were then returned to the plastic bag. It is known that the lubricant flows readily and, when it is in contact with any oil-absorbent material, it will "wick" away. Since the HDL environment test area carries a heavy work load, it is postulated that the S&A units were removed from their pouches before the test, placed on a workbench (perhaps on paper towels) and, because of other work commitments, were not tested immediately. Lubricant loss under these circumstances would account for the additional fretting products, the exceptional dryness of the material, and a noted lack of oil remaining in the S&A unit. Although this is a hypothesis and cannot be proven, it does correlate with known facts and does have merit as an explanation.

7.2.2 Chemical Analysis

Table 7 (an excerpt from table D-1, app D) shows the type and amount of metal particles and the amount of oil that were observed in the chemical-mechanical analysis. At the time these results were obtained, the analysis technique had been perfected; thus, these results are quite reliable. It can be observed that units "as delivered" do contain some metal particles (0.117 ± 0.0004 gms). More important, however, is the fact that among the three samples there is more than a 2:1 ratio in the amount of oil present between the least- and best-lubricated units. The variation in lubrication of other units and its effect on TTA performance must be questioned.

7.2.3 Relevancy to Future Tests

Since lubrication appears to play a major role in vibratory damage results, an assessment of its importance should be determined. This is especially applicable where another parameter is being evaluated (as herein, RTV test versus standard TV test), and the lubrication appears to be a significant factor in determining wear damage. A consideration for future tests might include ultrasonic cleaning of all units and precise lubrication of critical bearings and pivots before actual testing.

7.3 Chemical-Mechanical Analysis

This method was developed into a precise, valuable analysis tool. Because of its credibility, analysis of RTV test data (5, 10, 15, and 20 *g*) directed attention to the fact that at higher *g* levels, damage occurred as a distortion of parts and enlargement of pivots and holes rather than as abraded by-products. Analysis data provided a quantitative measurement that confirmed visual observations. Current thinking is that this analysis tool will see more use in the future for analysis of the types of debris that result from vibratory testing. In such use, it would lead designers to consider different materials or designs to minimize part wear at critical surfaces and pivots.

7.4 Mechanical Inspection

Observations, test results, and the limited use of dimensional measurements that were made indicate that precise determination of damage effects in the future will rely heavily on precise mechanical inspection. Once critical component dimensions are delineated, pre- and post-test measurements will have to be made. Manufacturer's tolerances cannot be used as a reliable benchmark. Although this suggested detailed approach may appear to be costly in time, precise measurement data are necessary for accurate reliable analysis of test method applicability. In addition, such modifications in procedure as more uniform lubrication of test units, more precisely controlled storage and handling parameters, etc., will allow use of few test samples or, conversely, for a given number of units, will yield more consistent, accurate, and precise results.

7.5 Spectral Analysis, Sinusoidal Drive, Random Vibration Drive

7.5.1 Spectral Analysis

Analysis of the harmonic or sub-band response to the swept sinusoidal drive has proved informative. At this point, precise conclusions cannot be made, nor is it necessary to be able to do so. It is immaterial whether wear occurs because of structural resonances or because of component resonant response — the net effect is observable damage. Noteworthy however, is the observation that most response (acceleration excursions) occur in the band between 100 and 250 Hz or, being more liberal, even as wide a band as 50 to 300 Hz. Further study is necessary to be more definitive but, for now, some interesting conjectures can be made regarding future types of testing and a related savings in test time.

7.5.2 Sinusoidal Drive

If it is assumed that negligible damage occurs outside the 100- to 250-Hz band (or perhaps 50 to 300 Hz), it follows that test time spent sweeping outside this region might be unnecessary. Time spent between 92.4 and 270 Hz is 7 minutes (26 minus 19 min) and between 50.0 and 315 Hz is 12 minutes (27 minus 15 min) (see app A, table A-1). Of the present swept frequency test cycle, 7 minutes duration is 23 percent and 12 minutes is 40 percent. An experimental investigation to check this hypothesis appears warranted.

7.5.3 Random Vibration Drive

Tests performed so far are very promising — certainly, feasibility of the method and the savings in test time have been demonstrated (1 hour versus 12 hours).

However, experimental and mathematical calculations (sect. 4.2) predicted 1.6 hours of testing for RTV versus 4 hours for standard TV testing. It should be recalled that the calculated value was based on $\sim_R$ over the 5- to 500-Hz band. If the assumption about sub-band relevancy is carried forward, the product of the 100- to 250-Hz band value (23-percent test time) and the $\sim_R$ time ratio (1.6 versus 4.0 hours = 40 percent) yields a value of 9.2 percent, a crudely derived but interesting result.

Details as to amplitude levels, spectral content, and test duration will have to be determined. However, considerable leeway exists in the parameters available for adjustment so as to justify the optimism that equivalency can be demonstrated while considerable time is saved.

8. CONCLUSIONS

Several conclusions can be drawn from the procedures reported on here.

- Processing of the S&A units (especially regarding lubrication), storage, and handling can be a dominant factor in shaping the outcome of the MIL-STD TV tests.

- The standard spin test and the measurement of TTA proved to be a realistic, valid measure of the S&A sustained damage.
- The chemical-physical debris analysis that was finally developed is a precise quantitative measurement method that provided insight into the cleanliness and lubrication of units. It provided a major clue as to the type of damage sustained at the higher g levels in the RTV tests (hole enlargement, dimensional changes, etc., rather than abrasion and fretting products). This chemical-physical technique will probably in the future be reserved almost entirely for analysis of the abraded material.
- Visual observation of units at low magnification sufficed to verify results of the spinner arming tests. However, quantitative analysis of "equivalent" damage sustained by units as a result of varying TV test parameters will be most meaningful if sophisticated dimensional measurement equipment is used.
- Principles and techniques developed by this project show considerable promise as a design analysis test for ordnance materiel exposed to vibratory environments.

9. RECOMMENDATIONS

Feasibility of the proposed RTV test as a substitute (equivalent) replacement for the MIL-STD 331 TV test has been demonstrated; equally as important, it has been shown that test time for comparable damage to the M732 S&A module can be achieved in less than one-half of the test time now required. It is therefore recommended that, as an absolute minimum effort, this program be continued. Specific test criteria for RTV testing could then be established which will be shown to be equivalent to the damage sustained by units in the current MIL-STD 331, Method 119, TV test. Additional support of this proposal would allow for collection and utilization of available field environment test records (TV tapes, records, etc.) for spectral analysis, followed by RTV test specifications that would be fine tuned for the "real world." Additional areas for development could then include design (or at least analysis for relevancy) of similar tests for other ordnance materiel.

10. SUMMARY

Specifications were to be derived for a random vibration test procedure that would replace the current MIL-STD 331, Method 119, swept sinusoidal TV test; the proposed test would be more realistic, would result in better field environment-qualified ordnance materiel, and, because of a shorter required test time, would be less costly.

The proposal called for the demonstration of equivalency between the new and old test methods by running each type of test on standard M732 S&A modules and then comparing and evaluating the results.

An experimental and mathematical analysis established a test time of 1.6 hours for RTV versus 4 hours for the standard TV test. Units were run at one of 4 g levels (5, 10, 15, and 20 g) in the RTV mode for 1 hour, versus 12 hours for the baseline test (standard TV). Damage levels were observed that spanned those obtained with the standard TV test, demonstrating feasibility of the method and sufficient flexibility for adjustment of parameters to warrant confidence that test specifications can be established with substantial savings in testing time. Further developments in this project, however, will require additional support and additional funding.

In the course of this program, several accomplishments were made that are basic to continuing work, and an event was noted that perhaps ranks as important as the outcome of this project itself. The event referred to involves the lubrication of the S&A module. Two groups of eight units each from the same manufacturing lot were subjected to the MIL-STD test at different times; post-test results differed radically. The second group armed poorly if at all, exhibited much greater wear, and had very little lubricant. Since the units came from the same lot, lack of lubricant was attributed to loss through handling or storage. This occurrence should alert the ordnance materiel test community that apparently insignificant factors may play as important a role in test outcome as known major items of importance, or even the test procedure itself.

Some accomplishments follow.

(1) Development of a chemical-mechanical analysis procedure for assaying metal debris and oil residue in the S&A module.

(2) Development of transducer instrumentation and methods for definition of damage inflicting dominant frequency sub-bands.

(3) Determination of damage-prone surfaces and elements within the S&A and decision that precise dimensional measurements of S&A elements will yield maximum information with fewest test samples.

(4) Use and availability of a computer program for processing and for spectral analysis of TV test records.

To recapitulate, data obtained and analyzed to date justify the original premises and predictions for the proposed random vibration test procedure. Techniques and guidelines have been developed that will channel additional supporting work to a successful project conclusion. Further testing and project funding is required to substantiate and document a precisely defined test procedure.

APPENDIX A. — REVERSIBLE CYCLES IN MIL-STD TRANSPORTATION VIBRATION TESTS

A computer program was written to establish the numerical values of parameters f, N, and N_{Tot} as functions of test frequency and time. The program, a tabular listing that follows, shows the instantaneous numerical value of each of the parameters over 1-minute intervals within the 240-minute range and graphical plots of the sweep function and N_{Tot}.

To determine the equivalent test time for the proposed RTV test, a statistical cycle-reversal frequency about a specified mean or rms level of excitation had to be established. This was achieved in two independent ways—through evaluation of test data and by theoretical considerations.

FORTRAN IV   D06-01 SOURCE LISTING

```
C LOGLIN - COMPUTES TWO FUNCTIONS:
C
C    E(T)=3.*10.**(4.*(30.-ABS(AMOD(T,60.)-30.)))
C
C    N(T)=F0*3600.*(10.**(M*T)-1.)/(M*LN(10.))
C
C BOTH FROM 0 MIN. TO 240 MIN., T IS IN HOURS
C    F0=5.
C    M=4.
C    LN(10.)=2.302585
C
         DIMENSION XF(241),XN(241),BASE(241),XOFF(241)
         DIMENSION XL1(2),XL2(2),YL1(2),YL2(2)
         DATA XL1/'GRAP','H 1 '/
         DATA XL2/'GRAP','H 2 '/
         DATA YL1/'LOGS','CALE'/
         DATA YL2/'LOGS','CALE'/
         DATA LENXL1,LENXL2,LENYL1,LENYL2/4*8/
C
C ATTACH OUTPUT LUN 4
         WRITE(5,5)
  5      FORMAT(' ENTER OUTPUT DEVICE OR FILE')
         CALL OPENFI(5,4)
C OPTION: DIAGNOSTIC OUTPUT
         WRITE(5,6)
  6      FORMAT(' ENTER 1 FOR EXTRA DIAGNOSTIC OUTPUT')
         READ(5,110)IFLAG
C DO FIRST EQUATION:
         X=0.
         XINC=1.
C
         DO 40 I=1,241
         XF(I)=5.*10.**(4.*X/60.)
         X=X+XINC
         IF (X .GE. 30.)XINC=-1.
         IF (X .LE. 0.)XINC=1.
  40     CONTINUE
C DO SECOND EQUATION
C SETUP
         XBASE=0.
         XINC=1.
         X=0.
C LOOP
         DO 44 I=1,241
         XN(I)=XBASE+XINC*(36000.*(10.**(X/15.)-1.)/(8*2.3026))
         BASE(I)=XBASE
         XOFF(I)=XINC*(36000.*(10.**(X/15.)-1.)/2.3026)
         IF (X .LT. 30.) GO TO 42
           XBASE=XBASE+XN(31)+XN(31)
           XINC=-1.
  42     IF (X .GT. 0) GO TO 44
           XINC=1.
  44     X=X+XINC
C
         J=1
         DO 200 I=1,8
  110    FORMAT(I1)
```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```
FORTRAN IV      D06-01   SOURCE LISTING

              IF (IFLAG .EQ. 0)WRITE(4,120)
        120   FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N')
              IF (IFLAG .EQ. 1) WRITE(4,121)
        121   FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N',10X,'BASE',
             1       8X,'OFFSET')
        C
              K1=J+29
              IF (K1 .EQ. 240) K1=241
              DO 160 K=J,K1
              IF (IFLAG .EQ. 0) GO TO 140
              WRITE(4,135)K-1,XF(K),XN(K),ALOG(XN(K)),BASE(K),XOFF(K)
        135   FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4)
              GO TO 160
        140   WRITE(4,165)K-1,XF(K),XN(K),ALOG(XN(K))
        160   CONTINUE
        165   FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4)
        200   J=K1+1
        C PROMPT FOR GRAPHS
              WRITE(5,590)
        590   FORMAT(' ENTER 1 TO OUTPUT GRAPHS')
              READ(5,110)IJ
              IF (IJ .EQ. 0) STOP
        C OUTPUT 2 GRAPHS
              WRITE(5,600)
        600   FORMAT(' SPECIFY OUTPUT DEVICE FOR GRAPHS')
              CALL OPENFI(5,1)
              CALL SETPDQ
              CALL INIT(2.,1.5)
              CALL SCREEN
              CALL ENTGRA
        C GRAPH 1
              CALL LOGQCA(XF,241,6.,1,1)
              CALL QCALE(0.,240.,6.,SF,VLO,0)
              CALL YLOGAX(YL1,LENYL1,6.)
              CALL XAXIS(XL1,LENXL1,6.)
              IPEN=3
              DO 610 I=1,241
              CALL DRAW(FLOAT(I-1),XF(I),IPEN,2)
        610   IPEN=1
              CALL EXITGR
        C GRAPH 2
              READ(5,110)IJ
              CALL SCREEN
              CALL ENTGRA
              CALL LOGQCA(XN,241,6.,1,1)
              CALL YLOGAX(YL2,LENYL2,6.)
              CALL XAXIS(XL2,LENXL2,6.)
              IPEN=3
              DO 620 I=1,241
              CALL DRAW(FLOAT(I-1),XN(I),IPEN,2)
        620   IPEN=1
              CALL EXITGR
              READ(5,110)IJ
              STOP
              END
```

```
HDL SUPER FORTRAN V2-4
LOGLIN.FTN       /TR:BLOCKS/WR

      C LOGLIN - COMPUTES TWO FUNCTIONS:
      C
      C   F(T)=5.*10.**(4.*(30.-ABS(AMOD(T,60.)-30.)))
      C
      C   N(T)=F0*3600.*(10.**(M*T)-1.)/(M*LN(10.))
      C
      C BOTH FROM 0 MIN. TO 240 MIN., T IS IN HOURS
      C   F0=5.
      C   M=4.
      C   LN(10.)=2.302585
      C
                DIMENSION XF(241),XN(241),BASE(241),XOFF(241)
                DIMENSION XL1(2),XL2(2),YL1(2),YL2(2)
                DATA XL1/'GRAP','H 1 '/
      C       DATA XL2/'GRAP','H 2 '/
              DATA XL2/'    ','    '/
                DATA YL1/'LOGS','CALE'/
      C       DATA YL2/'LOGS','CALE'/
              DATA YL2/'    ','    '/
                DATA LENXL1,LENXL2,LENYL1,LENYL2/4*8/
      C
      C ATTACH OUTPUT LUN 4
                WRITE(5,5)
      5         FORMAT('$ENTER OUTPUT DEVICE OR FILE: ')
                CALL FILASN(4)
      C OPTION: DIAGNOSTIC OUTPUT
                WRITE(5,6)
      6         FORMAT('$ENTER 1 FOR EXTRA DIAGNOSTIC OUTPUT: ')
                READ(5,110)IFLAG
      C DO FIRST EQUATION:
                X=0.
                XINC=1.
      C
                DO 40 I=1,241
                XF(I)=5.*10.**(4.*X/60.)
                X=X+XINC
                IF (X .GE. 30.)XINC=-1.
                IF (X .LE. 0.)XINC=1.
      40        CONTINUE
      C DO SECOND EQUATION
      C SETUP
                XBASE=0.
                XINC=1.
                X=0.
      C LOOP
                DO 44 I=1,241
                XN(I)=XBASE+XINC*(36000.*(10.**(X/15.)-1.)/(8*2.3026))
                BASE(I)=XBASE
                XOFF(I)=XINC*(36000.*(10.**(X/15.)-1.)/2.3026)
                IF (X .LT. 30.) GO TO 42
                  XBASE=XBASE+XN(31)+XN(31)
                  XINC=-1.
      42        IF (X .GT. 0) GO TO 44
                  XINC=1.
      44        X=X+XINC
      C
                J=1
                DO 200 I=1,8
      110       FORMAT(I1)
                IF (IFLAG .EQ. 0)WRITE(4,120)
      120       FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N')
```

```
               IF (IFLAG .EQ. 1) WRITE(4,121)
      121      FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N',10X,'BASE',
               1       8X,'OFFSET')
      C
               K1=J+29
               IF (K1 .EQ. 240) K1=241
               DO 160 K=J,K1
               IF (IFLAG .EQ. 0) GO TO 140
               WRITE(4,135)K-1,XF(K),XN(K),ALOG(XN(K)),BASE(K),XOFF(K)
      135      FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4)
               GO TO 160
      140      WRITE(4,165)K-1,XF(K),XN(K),ALOG(XN(K))
      160      CONTINUE
      165      FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4)
      200      J=K1+1
      C PROMPT FOR GRAPHS
               WRITE(5,590)
      590      FORMAT(' ENTER 1 TO OUTPUT GRAPHS')
               READ(5,110)IJ
               IF (IJ .EQ. 0) STOP
      C OUTPUT 2 GRAPHS
               WRITE(5,600)
      600      FORMAT('#SPECIFY OUTPUT DEVICE FOR GRAPHS: ')
               CALL FILASN(1)
               CALL SETPDQ
               CALL INIT(2.,1.5)
               CALL SCREEN
               CALL ENTGRA
      C GRAPH 1
               CALL LOGOCA(XF,241,6.,1,1)
               CALL OCALE(0.,240.,6.,SF,VLO,0)
               CALL YLOGAX(YL1,LENYL1,6.)
               CALL XAXIS(XL1,LENXL1,6.)
               IPEN=3
               DO 610 I=1,241
               CALL DRAW(FLOAT(I-1),XF(I),IPEN,2)
      610      IPEN=1
               CALL EXITGR
      C GRAPH 2
               READ(5,110)IJ
               CALL SCREEN
               CALL ENTGRA
               CALL LOGOCA(XN,241,6.,1,1)
               CALL YLOGAX(YL2,LENYL2,6.)
               CALL XAXIS(XL2,LENXL2,6.)
               IPEN=3
               DO 620 I=1,241
               CALL DRAW(FLOAT(I-1),XN(I),IPEN,2)
      620      IPEN=1
               CALL EXITGR
               READ(5,110)IJ
               STOP
               END

PROGRAM SECTIONS

 NAME        SIZE          ATTRIBUTES

#CODE1   002206    579   RW,I,CON,LCL
#PDATA   000060     24   RW,D,CON,LCL
#IDATA   000566    187   RW,D,CON,LCL
#VARS    007532   1965   RW,D,CON,LCL
#TEMPS   000004      2   RW,D,CON,LCL   TOTAL SPACE ALLOCATED = 012612   2757

                                          ,LP:=LOGLIN.FTN
```

```
C LOGLIN - COMPUTES TWO FUNCTIONS:
C
C   F(T)=5.*10.**(4.*(30.-ABS(AMOD(T,60.)-30.)))
C
C   N(T)=F0*3600.*(10.**(M*T)-1.)/(M*LN(10.))
C
C BOTH FROM 0 MIN. TO 240 MIN., T IS IN HOURS
C   F0=5.
C   M=4.
C   LN(10.)=2.302585
C
      DIMENSION XF(241),XN(241),BASE(241),XOFF(241)
      DIMENSION XL1(2),XL2(2),YL1(2),YL2(2)
      DATA XL1/'GRAP','H 1 '/
C    DATA XL2/'GRAP','H 2 '/
     DATA XL2/'    ','    '/
      DATA YL1/'LOGS','CALE'/
C    DATA YL2/'LOGS','CALE'/
     DATA YL2/'    ','    '/
      DATA LENXL1,LENXL2,LENYL1,LENYL2/4*8/
C
C ATTACH OUTPUT LUN 4
      WRITE(5,5)
5     FORMAT('$ENTER OUTPUT DEVICE OR FILE: ')
      CALL FILASN(4)
C OPTION: DIAGNOSTIC OUTPUT
      WRITE(5,6)
6     FORMAT('$ENTER 1 FOR EXTRA DIAGNOSTIC OUTPUT: ')
      READ(5,110)IFLAG
C DO FIRST EQUATION:
      X=0.
      XINC=1.
C
      DO 40 I=1,241
      XF(I)=5.*10.**(4.*X/60.)
      X=X+XINC
      IF (X .GE. 30.)XINC=-1.
      IF (X .LE. 0.)XINC=1.
40    CONTINUE
C DO SECOND EQUATION
C SETUP
      XBASE=0.
      XINC=1.
      X=0.
C LOOP
      DO 44 I=1,241
      XN(I)=XBASE+XINC*(36000.*(10.**(X/15.)-1.)/(8*2.3026))
      BASE(I)=XBASE
      XOFF(I)=XINC*(36000.*(10.**(X/15.)-1.)/2.3026)
      IF (X .LT. 30.) GO TO 42
        XBASE=XBASE+XN(31)+XN(31)
        XINC=-1.
42    IF (X .GT. 0) GO TO 44
        XINC=1.
44    X=X+XINC
C
      J=1
      DO 200 I=1,8
110   FORMAT(I1)
      IF (IFLAG .EQ. 0)WRITE(4,120)
120   FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N')
      IF (IFLAG .EQ. 1) WRITE(4,121)
121   FORMAT('1 INDEX',5X,'FREQ',10X,'N',9X,'LOG N',10X,'BASE',
      1      8X,'OFFSET')
```

```
C
        K1=J+29
        IF (K1 .EQ. 240) K1=241
        DO 160 K=J,K1
        IF (IFLAG .EQ. 0) GO TO 140
        WRITE(4,135)K-1,XF(K),XN(K),ALOG(XN(K)),BASE(K),XOFF(K)
135     FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4,2X,G11.4)
        GO TO 160
140     WRITE(4,165)K-1,XF(K),XN(K),ALOG(XN(K))
160     CONTINUE
165     FORMAT(3X,I3,3X,G11.4,2X,G11.4,2X,G11.4)
200     J=K1+1
C PROMPT FOR GRAPHS
        WRITE(5,590)
590     FORMAT(' ENTER 1 TO OUTPUT GRAPHS')
        READ(5,110)IJ
        IF (IJ .EQ. 0) STOP
C OUTPUT 2 GRAPHS
        WRITE(5,600)
600     FORMAT('$SPECIFY OUTPUT DEVICE FOR GRAPHS: ')
        CALL FILASN(1)
        CALL SETPDQ
        CALL INIT(2.,1.5)
        CALL SCREEN
        CALL ENTGRA
C GRAPH 1
        CALL LOGQCA(XF,241,6.,1,1)
        CALL QCALE(0.,240.,6.,SF,VLO,0)
        CALL YLOGAX(YL1,LENYL1,6.)
        CALL XAXIS(XL1,LENXL1,6.)
        IPEN=3
        DO 610 I=1,241
        CALL DRAW(FLOAT(I-1),XF(I),IPEN,2)
610     IPEN=1
        CALL EXITGR
C GRAPH 2
        READ(5,110)IJ
        CALL SCREEN
        CALL ENTGRA
        CALL LOGQCA(XN,241,6.,1,1)
        CALL YLOGAX(YL2,LENYL2,6.)
        CALL XAXIS(XL2,LENXL2,6.)
        IPEN=3
        DO 620 I=1,241
        CALL DRAW(FLOAT(I-1),XN(I),IPEN,2)
620     IPEN=1
        CALL EXITGR
        READ(5,110)IJ
        STOP
        END
```

TABLE A-1. NUMBER OF ACCUMULATED REVERSALS AS A FUNCTION OF TIME AND FREQUENCY — MIL-STD 331, METHOD 119, PROCEDURE I

INDEX	FREQ	N	LOG N	INDEX	FREQ	N	LOG N
0	5.000	0.0000	0.0000	60	5.000	0.3870E+06	12.87
1	5.830	324.2	5.782	61	5.830	0.3873E+06	12.87
2	6.797	702.3	6.554	62	6.797	0.3877E+06	12.87
3	7.924	1143.	7.041	63	7.924	0.3881E+06	12.87
4	9.239	1657.	7.413	64	9.239	0.3886E+06	12.87
5	10.77	2256.	7.721	65	10.77	0.3892E+06	12.87
6	12.56	2955.	7.991	66	12.56	0.3899E+06	12.87
7	14.64	3769.	8.235	67	14.64	0.3907E+06	12.88
8	17.07	4719.	8.459	68	17.07	0.3917E+06	12.88
9	19.91	5826.	8.670	69	19.91	0.3928E+06	12.88
10	23.21	7117.	8.870	70	23.21	0.3941E+06	12.88
11	27.06	8622.	9.062	71	27.06	0.3956E+06	12.89
12	31.55	0.1038E+05	9.247	72	31.55	0.3973E+06	12.89
13	36.78	0.1242E+05	9.427	73	36.78	0.3994E+06	12.90
14	42.88	0.1481E+05	9.603	74	42.88	0.4018E+06	12.90
15	50.00	0.1759E+05	9.775	75	50.00	0.4045E+06	12.91
16	58.30	0.2083E+05	9.944	76	58.30	0.4078E+06	12.92
17	67.97	0.2461E+05	10.11	77	67.97	0.4116E+06	12.93
18	79.24	0.2902E+05	10.28	78	79.24	0.4160E+06	12.94
19	92.39	0.3416E+05	10.44	79	92.39	0.4211E+06	12.95
20	107.7	0.4015E+05	10.60	80	107.7	0.4271E+06	12.96
21	125.6	0.4714E+05	10.76	81	125.6	0.4341E+06	12.98
22	146.4	0.5528E+05	10.92	82	146.4	0.4422E+06	13.00
23	170.7	0.6478E+05	11.08	83	170.7	0.4517E+06	13.02
24	199.1	0.7585E+05	11.24	84	199.1	0.4628E+06	13.05
25	232.1	0.8875E+05	11.39	85	232.1	0.4757E+06	13.07
26	270.6	0.1038E+06	11.55	86	270.6	0.4908E+06	13.10
27	315.5	0.1214E+06	11.71	87	315.5	0.5083E+06	13.14
28	367.8	0.1418E+06	11.86	88	367.8	0.5288E+06	13.18
29	428.8	0.1657E+06	12.02	89	428.8	0.5526E+06	13.22
30	500.0	0.1935E+06	12.17	90	500.0	0.5804E+06	13.27
31	428.8	0.2213E+06	12.31	91	428.8	0.6082E+06	13.32
32	367.8	0.2451E+06	12.41	92	367.8	0.6321E+06	13.36
33	315.5	0.2656E+06	12.49	93	315.5	0.6526E+06	13.39
34	270.6	0.2831E+06	12.55	94	270.6	0.6701E+06	13.42
35	232.1	0.2982E+06	12.61	95	232.1	0.6852E+06	13.44
36	199.1	0.3111E+06	12.65	96	199.1	0.6981E+06	13.46
37	170.7	0.3222E+06	12.68	97	170.7	0.7091E+06	13.47
38	146.4	0.3317E+06	12.71	98	146.4	0.7186E+06	13.49
39	125.6	0.3398E+06	12.74	99	125.6	0.7268E+06	13.50
40	107.7	0.3468E+06	12.76	100	107.7	0.7338E+06	13.51
41	92.39	0.3528E+06	12.77	101	92.39	0.7397E+06	13.51
42	79.24	0.3579E+06	12.79	102	79.24	0.7449E+06	13.52
43	67.97	0.3623E+06	12.80	103	67.97	0.7493E+06	13.53
44	58.30	0.3661E+06	12.81	104	58.30	0.7531E+06	13.53
45	50.00	0.3694E+06	12.82	105	50.00	0.7563E+06	13.54
46	42.88	0.3721E+06	12.83	106	42.88	0.7591E+06	13.54
47	36.78	0.3745E+06	12.83	107	36.78	0.7615E+06	13.54
48	31.55	0.3766E+06	12.84	108	31.55	0.7635E+06	13.55
49	27.06	0.3783E+06	12.84	109	27.06	0.7653E+06	13.55
50	23.21	0.3798E+06	12.85	110	23.21	0.7668E+06	13.55
51	19.91	0.3811E+06	12.85	111	19.91	0.7681E+06	13.55
52	17.07	0.3822E+06	12.85	112	17.07	0.7692E+06	13.55
53	14.64	0.3832E+06	12.86	113	14.64	0.7701E+06	13.55
54	12.56	0.3840E+06	12.86	114	12.56	0.7710E+06	13.56
55	10.77	0.3847E+06	12.86	115	10.77	0.7717E+06	13.56
56	9.239	0.3853E+06	12.86	116	9.239	0.7723E+06	13.56
57	7.924	0.3858E+06	12.86	117	7.924	0.7728E+06	13.56
58	6.797	0.3863E+06	12.86	118	6.797	0.7732E+06	13.56
59	5.830	0.3866E+06	12.87	119	5.830	0.7736E+06	13.56

TABLE A-1 (Cont'd)

INDEX	FREQ	N	LOG N
120	5.000	0.7739E+06	13.56
121	5.830	0.7742E+06	13.56
122	6.797	0.7746E+06	13.56
123	7.924	0.7751E+06	13.56
124	9.239	0.7756E+06	13.56
125	10.77	0.7762E+06	13.56
126	12.56	0.7769E+06	13.56
127	14.64	0.7777E+06	13.56
128	17.07	0.7786E+06	13.57
129	19.91	0.7797E+06	13.57
130	23.21	0.7810E+06	13.57
131	27.06	0.7825E+06	13.57
132	31.55	0.7843E+06	13.57
133	36.78	0.7863E+06	13.58
134	42.88	0.7887E+06	13.58
135	50.00	0.7915E+06	13.58
136	58.30	0.7947E+06	13.59
137	67.97	0.7985E+06	13.59
138	79.24	0.8029E+06	13.60
139	92.39	0.8081E+06	13.60
140	107.7	0.8141E+06	13.61
141	125.6	0.8210E+06	13.62
142	146.4	0.8292E+06	13.63
143	170.7	0.8387E+06	13.64
144	199.1	0.8498E+06	13.65
145	232.1	0.8627E+06	13.67
146	270.6	0.8777E+06	13.69
147	315.5	0.8953E+06	13.70
148	367.8	0.9157E+06	13.73
149	428.8	0.9396E+06	13.75
150	500.0	0.9674E+06	13.78
151	428.8	0.9952E+06	13.81
152	367.8	0.1019E+07	13.83
153	315.5	0.1040E+07	13.85
154	270.6	0.1057E+07	13.87
155	232.1	0.1072E+07	13.89
156	199.1	0.1085E+07	13.90
157	170.7	0.1096E+07	13.91
158	146.4	0.1106E+07	13.92
159	125.6	0.1114E+07	13.92
160	107.7	0.1121E+07	13.93
161	92.39	0.1127E+07	13.93
162	79.24	0.1132E+07	13.94
163	67.97	0.1136E+07	13.94
164	58.30	0.1140E+07	13.95
165	50.00	0.1143E+07	13.95
166	42.88	0.1146E+07	13.95
167	36.78	0.1148E+07	13.95
168	31.55	0.1150E+07	13.96
169	27.06	0.1152E+07	13.96
170	23.21	0.1154E+07	13.96
171	19.91	0.1155E+07	13.96
172	17.07	0.1156E+07	13.96
173	14.64	0.1157E+07	13.96
174	12.56	0.1158E+07	13.96
175	10.77	0.1159E+07	13.96
176	9.239	0.[illegible]59E+07	13.96
177	7.924	0.1160E+07	13.96
178	6.797	0.1160E+07	13.96
179	5.830	0.1161E+07	13.96
180	5.000	0.1161E+07	13.96
181	5.830	0.1161E+07	13.96
182	6.797	0.1162E+07	13.97
183	7.924	0.1162E+07	13.97
184	9.239	0.1163E+07	13.97
185	10.77	0.1163E+07	13.97
186	12.56	0.1164E+07	13.97
187	14.64	0.1165E+07	13.97
188	17.07	0.1166E+07	13.97
189	19.91	0.1167E+07	13.97
190	23.21	0.1168E+07	13.97
191	27.06	0.1169E+07	13.97
192	31.55	0.1171E+07	13.97
193	36.78	0.1173E+07	13.98
194	42.88	0.1176E+07	13.98
195	50.00	0.1178E+07	13.98
196	58.30	0.1182E+07	13.98
197	67.97	0.1185E+07	13.99
198	79.24	0.1190E+07	13.99
199	92.39	0.1195E+07	13.99
200	107.7	0.1201E+07	14.00
201	125.6	0.1208E+07	14.00
202	146.4	0.1216E+07	14.01
203	170.7	0.1226E+07	14.02
204	199.1	0.1237E+07	14.03
205	232.1	0.1250E+07	14.04
206	270.6	0.1265E+07	14.05
207	315.5	0.1282E+07	14.06
208	367.8	0.1303E+07	14.08
209	428.8	0.1327E+07	14.10
210	500.0	0.1354E+07	14.12
211	428.8	0.1382E+07	14.14
212	367.8	0.1406E+07	14.16
213	315.5	0.1426E+07	14.17
214	270.6	0.1444E+07	14.18
215	232.1	0.1459E+07	14.19
216	199.1	0.1472E+07	14.20
217	170.7	0.1483E+07	14.21
218	146.4	0.1493E+07	14.22
219	125.6	0.1501E+07	14.22
220	107.7	0.1508E+07	14.23
221	92.39	0.1514E+07	14.23
222	79.24	0.1519E+07	14.23
223	67.97	0.1523E+07	14.24
224	58.30	0.1527E+07	14.24
225	50.00	0.1530E+07	14.24
226	42.88	0.1533E+07	14.24
227	36.78	0.1535E+07	14.24
228	31.55	0.1537E+07	14.25
229	27.06	0.1539E+07	14.25
230	23.21	0.1541E+07	14.25
231	19.91	0.1542E+07	14.25
232	17.07	0.1543E+07	14.25
233	14.64	0.1544E+07	14.25
234	12.56	0.1545E+07	14.25
235	10.77	0.1546E+07	14.25
236	9.239	0.1546E+07	14.25
237	7.924	0.1547E+07	14.25
238	6.797	0.1547E+07	14.25
239	5.830	0.1547E+07	14.25
240	5.000	0.1548E+07	14.25

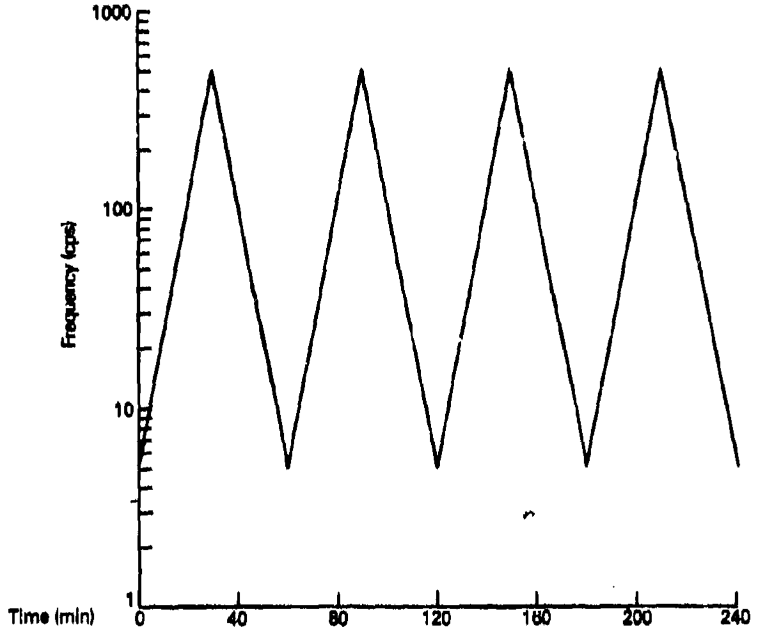


Figure A-1. Sinusoidal sweep for MIL-STD 331, Method 119, Procedure I TV test.

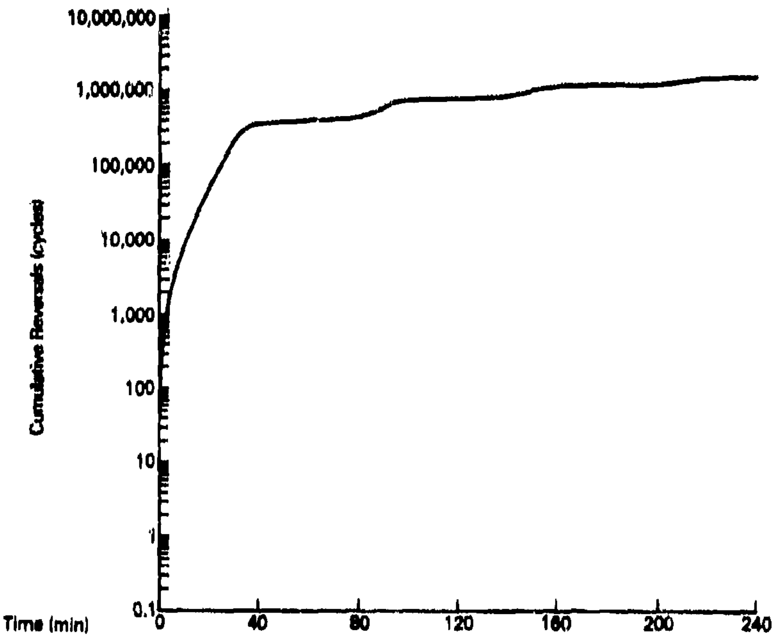


Figure A-2. Number of reversible cycles accumulated during the MIL-STD 331, Method 119, Procedure I TV test.

APPENDIX B. — HDL MECHANICAL INSPECTION FACILITY.

The mechanical inspection facility provides a dimensional inspection capability for making intricate, precise measurements of component parts and assemblies, whether made in-house or by outside contractors. Services are furnished to the Industrial Engineering Group by first-article sampling testing and government acceptance gage calibration, and to the Calibration and Standards Branch by calibration of measurement instruments. Accuracy of measurement is ensured by the use of high-precision, computer-assisted electronic measuring equipment. All measuring equipment is calibrated on a regular scheduled basis by comparison to primary standards, traceable to the U.S. National Bureau of Standards.

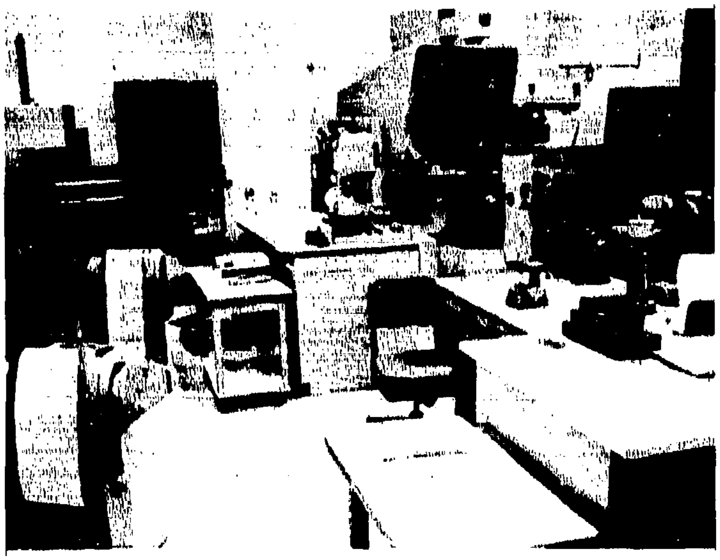


Figure B-1. HDL Mechanical Inspection Facility.

Major items of inspection equipment and their capabilities are as follows.

- Coordinate measuring machine; three axis Capacity, 30 in. X axis, 20 in. Y axis, 16 in. Z axis, Accuracy, 0.0002 in.; Resolution, 0.0001 in.

- Coordinate measuring machine; three axis Capacity, 24 in. X axis, 18 in. Y axis, 8 in. Z axis, Accuracy, 0.0005 in.; Resolution, 0.0001 in.

- Viewing screen scope, coordinate measuring machine attachment, Magnification, 10:1 and 20:1

- 30 in. Optical contour projector Digital readout, 0.0001 in. Resolution; Magnification, 10X to 100X

- 14 in. Optical contour projector Micrometer readout, 0.0001 in. Resolution; Magnification, 10X to 100X

- Profilometer, linear surface measurement RMS, 0.003 in., 0.010 in., 0.030 in. cutoff selector

- Optical depth gage Capacity, 10 in. in 1 in. increments; Accuracy, 0.000050 in.

- Toolmakers' microscope Digital readout, 0.0001 in.; Resolution; Magnification, 50:1

- Linear measuring machine Accuracy, 0.000010 in.

- Supermicrometer P&W Accuracy, 0.0001 in.

- Internal-external measuring machine Capacity — internal, 0.125 to 12 in.; external, 0 to 10 in.; Accuracy, 0.000001 in.

- Concentricity and surface analyzer Roundness responses, 0 to 15, 50, 150, or 500 CPR average roughness; Width cutoff, 0.003, 0.010, 0.030 in.; tracing, 0.005 in. per s; MM switching, 0.05, 0.21, and 0.53 mm; tracing, 0.105 mm/s; Accuracy, 0.0000025 in.

- **Hardness tester, Rockwell**
  Hardened steel and hard alloys
- **Hardness tester, Rockwell superficial**
  Unhardened steel, soft tempered steel, grey and malleable cast iron, nonferrous metals
- **Optical dividing head**
  Accuracy, 2 s of arc
- **Spring precision load testers**
  Compression and tension
- **Electronic height comparison gage**
  Accuracy, 0.00001 in.
- **Gage Blocks, Class AAA**
  Calibration traceable to the U.S. National Bureau of Standards

APPENDIX C. – MANUFACTURER'S SPECIFICATION SHEETS.

The manufacturer's specification sheets for the triaxial accelerometer and the strain gage are contained in this appendix.

APPENDIX C-1. — MANUFACTURER'S PRODUCT DATA SHEET

MODEL 23

850 milligram Microminiature

PICOTRIAX® ACCELEROMETER

General Description

The Endevco® Model 23 is an extremely small, adhesive mounted triaxial accelerometer. Three piezoelectric transducers are mounted in mutually perpendicular axes to provide a response to motion in any direction. The small mass of the Model 23 allows it to measure the vibration characteristics of small test specimens or lightweight, thin structures, reducing effectively any loading effects.

Featuring a broad frequency response and wide range of temperature, the accelerometer also provides excellent mechanical isolation from case and cable strain, and low pyroelectric sensitivity. Three low-noise, field-replaceable cables exit from a single face of the transducer. They share a common connection with the case to provide a shield for the three sensing elements. The case is insulated from the mounting structure by a hard anodized surface. If any axis is damaged in use or handling, it can be replaced by the factory.

Specifications for Model 23 Accelerometer
(According to ANSI and ISA Standards)

DYNAMIC (each axis)

Charge Sensitivity[1]	0.4 pC/g, nominal; 0.3 pC/g, minimum
Voltage Sensitivity[2]	1.6 mV/g, nominal
Frequency Response (charge)[1]	+5% nominal, −9%, +7% maximum, 5 to 10 000 Hz, reference 100 Hz.
Mounted Resonance Frequency	50 000 Hz nominal
Transverse Sensitivity	5% maximum
Amplitude Linearity, Range	Sensitivity increases approximately 1% per 250 pk p, 0 to 2000 g
Zero Shift[4]	1% of reading per 1000 g, approximately, 0 to 2000 g.

ELECTRICAL (each axis)

Transducer Capacitance	230 pF nominal, including 8-inch 3003 cable assembly
Resistance	2000 MΩ minimum, at 72°F (22°C); 100 MΩ minimum, at 350°F (177°C)
Grounding	All three signal grounds common to case. Hard anodize provides insulation on the mounting surface.
Insulation Resistance[5]	100 MΩ minimum at 50 V dc
Insulation Capacitance[5]	50 pF nominal

[1]Use Endevco® Model 2640, 2680 or 2700 Series Charge Amplifiers

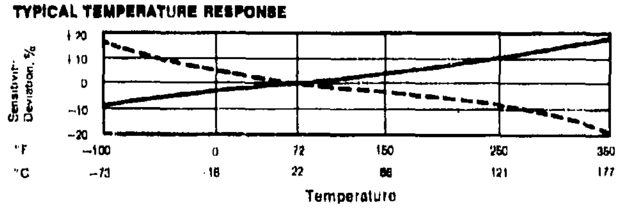
[2]With 8-inch 3003 cable assembly and 5 ft 3095A cable assembly

[3]In shock measurements, pulse duration for half-sine or triangular pulses should exceed 0.10 ms to avoid excessive high frequency ringing. See Endevco® Piezoelectric Accelerometer Manual

[4]Temporary zero shifts may be induced by shock. Such shifts will result in erroneous data if the signal is electronically integrated to obtain velocity or displacement information

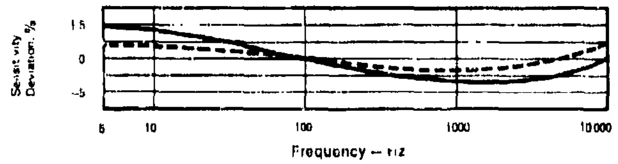
[5]Signal grounds (case) to mounting surface

TYPICAL TEMPERATURE RESPONSE



The solid curve shows the nominal charge-temperature response. The broken line shows the nominal voltage-temperature response with the 6 inch cable and 300 pF external capacitance.

TYPICAL FREQUENCY RESPONSE



The solid curve shows the typical charge-frequency response of the Model 23. The broken line shows the nominal voltage-frequency response with 350 megohm load and cable as supplied.

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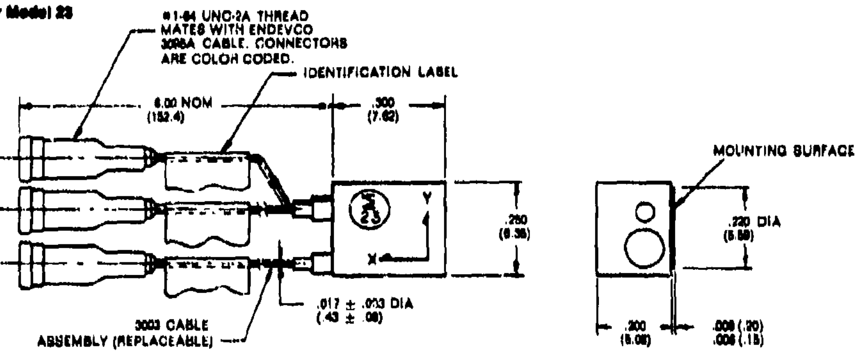
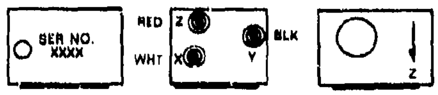
APPENDIX C-1. MANUFACTURER'S PRODUCT DATA SHEET(cont'd)

Specifications for Model 23





Polarity: Positive output for motion in direction of arrows.
Dimensions in inches and (millimeters).
Tolerances: .XX (X.X) = ±0.03 in. (±0.8 mm)
.XXX (X.XX) = ±0.010 in. (±0.25 mm)

PHYSICAL	
Design	Shear
Weight	850 milligram nominal, without cables; 1.7 grams milligram nominal, with 3 each 6 inch (15 cm) cable.
Crystal Material	Piezite® Type P-8
Case Material	Aluminum Alloy
Case Finish	Hard Anodize
Mounting	Adhesive. Use 18060 Accelerometer Removal Tool, provided.
Connectors	Special connectors mate with 3003 Cable Assembly.
Cable[1]	Replaceable Coaxial Cable Assembly, Model 3003-6, 6 inches (15 cm) long, CRES sheath with Kapton® polyimide jacket, 44 pF nominal.
Accessories Supplied	Three each Model 3095A-72 Low Noise Coaxial Cable Assembly, 6 ft. (1.8m) long, 180 pF nominal, with mating connector for 3003 assembly one end, 10-32 plug on the other end.
	18060 Accelerometer and Cable Removal Tool
Accessories Available	Model 3090A Low Noise Extension Cable Assemblies
	Model EJ34 Adapter, joins two 10-32 coaxial plugs
	Model 3093-12 Cable Assembly, similar to Model 3095 except 12 inches (0.3 m) long, and with 10-32 socket connector.
ENVIRONMENTAL	
Acceleration Limits[2]	10,000 g in any direction
Temperature	Operating: −100°F to 300°F (−73°C to 150°C)
	Maximum: −150°F to 350°F (−101°C to 177°C)

Base Strain Sensitivity	0.008 equivalent g nominal per μ strain
Magnetic Sensitivity	0.0009 equivalent g per gauss nominal at 100 gauss (10^{-2} T), 60 Hz
Acoustic Sensitivity	0.008 equivalent g approximately, at 140 dB[3] SPL
Humidity	Sealed with silicone compound. Tests indicate 48-hour protection against 97% RH at 140°F.
Altitude	Not affected.

[1]CAUTION: Removal of cable will expose accelerometer to environment. See manual for removal instructions.

[2]When subjected to high g, low frequency vibration, the cables must be tied down as close to the accelerometer as possible to prevent cable whip and eventual cable failure.

[3]White noise, 75 to 9800 Hz. 0 dB = 0.0002 microbar = 20 μ N/m² (Pa)

Continued product improvement necessitates that Endevco reserve the right to modify these specifications without notice.

RELIABILITY: Endevco maintains a program of constant surveillance over all products to ensure a high level of reliability. This program includes attention to reliability factors during product design, the support of stringent Quality Control requirements, and compulsory corrective action procedures. These measures, together with conservative specifications, have made the name Endevco synonymous with reliability.

CALIBRATION: Each axis is calibrated at room temperature for charge sensitivity at 100 Hz, capacitance of transducer and cable, maximum transverse sensitivity, and charge frequency response from 20 Hz to 4000 Hz. Other calibrations such as Temperature Response at −100°F (−73°C), room temperature, 250°F (121°C), and 350°F (177°C) are available on special order. See Calibration Service Bulletin No. 301.

ENDEVCO

RANCHO VIEJO ROAD · SAN JUAN CAPISTRANO, CA 92675 · TELEPHONE (714) 493-8181

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APPENDIX C-2. STRAIN GAGE MANUFACTURER'S SPECIFICATION SHEET.

Entran Devices, Inc.

BULLETIN ESG82-172

ES Series Semiconductor Strain Gages

The ES Series Semiconductor Strain Gages are available in both straight "Bar" and "U" type configurations. They are fabricated from P-Type silicon and designed to afford maximum flexibility with minimum stiffening to the operating system. Less than .0005" thick, the ES type gages are available in active gage lengths as small as 0.020" with an overall length of 0.040". The ES strain gages operate from -100°F to +500°F and will withstand a strain level of 2000 micro-strain without damage.

Entran will apply the ES gages to your prototype or OEM parts in any configuration from standard two or four arm Wheatstone bridges to custom specified arrangements. Areas as small as 1/8" in diameter can be gaged with a fully active four arm bridge. With constant voltage or constant current excitation, input strain can be directly converted to a millivolt output. Thermal zero shifts and thermal sensitivity shifts can be compensated to specifications as tight as 0.01%/°F over any operating range. Entran can individually tailor thermal compensation to each unit or system and supply the associated compensation circuitry in an external module or integral with the system.

Specifications for the ES Series Semiconductor Strain Gages are listed on the reverse side of this bulletin. For additional information or specific quotations, contact Entran directly.

145 Paterson Avenue
Little Falls, N.J. 07424
(201) 785-[illegible]

Acceleration/Force/Pressure

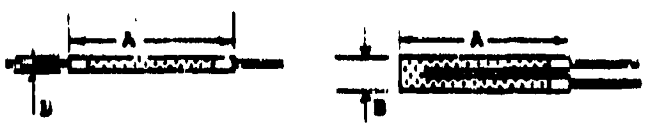
APPENDIX C-2. STRAIN GAGE MANUFACTURER'S SPECIFICATION SHEET. (Cont'd)

MODEL NO.	NOMINAL RESISTANCE OHMS	G.F. GAGE FACTOR	ACTIVE GAGE LENGTH	"A" TOTAL LENGTH	"B" WIDTH	TYPE
ESB-020-120	120	+140	0.020"	0.040"	0.010"	P
ESB-020-200	200	+110	0.020"	0.040"	0.006"	P
ESU-025-500	500	+135	0.025"	0.050"	0.014"	P
ESU-030-K500	500	+140	0.030"	0.060"	0.020"	P
ESU-030-500	500	+125	0.030"	0.060"	0.014"	P
ESU-030-K1000	1000	+155	0.030"	0.060"	0.020"	P
ESB-050-120	120	+110	0.050"	0.080"	0.006"	P
ESB-050-500	500	+145	0.050"	0.080"	0.006"	P
ESB-160-120	120	+120	0.160"	0.250"	0.020"	P
ESB-160-350	350	+135	0.160"	0.250"	0.006"	P
ESU-160-350	350	+120	0.160"	0.225"	0.024"	P
ESB-160-1000	1000	+140	0.160"	0.250"	0.006	P

MODEL NUMBER CODE

ESB	-	020	-	200
Configuration		Active Gages Length X .001"		Resistance Ohms

"ESB" Type "ESU" Type



GAGE TYPE: P-Type Silicon

THICKNESS: 0.0005" nom.

WATTAGE RATING: 40 mW

MAXIMUM STRAIN: 2000 Micro-Strain

LEAD WIRE: Gold or equivalent

Available in: Matched sets of four gages and OEM unmatched quantity pricing.

Contact Entran for specific quotation.

Table C-1. Equipment for S&A Device Vibration Test

AMPEX TAPE RECORDER	HDL 38662
CEC RECORDING OSCILLOGRAPH	HDL 30280
HONEYWELL GALVANOMETER AMPLIFIER	DOFL 17407, 17406
HP AMPLIFIER 465A	HDL 34987
GULTON TIMER	HDL 36915
KEITHLEY 102B DECADE ISOLATION AMPLIFIER	HDL 28477
KEITHLEY 102B DECADE ISOLATION AMPLIFIER	HDL 28476
HP 427 AC-DC VM	HDL 39412
LING SHAKER	
ENDEVCO CHARGE AMPLIFIER 2730	
ENDEVCO SHOCK AMPLIFIER 2718A	HDL 29973
ENDEVCO SHOCK AMPLIFIER 2718A	HDL 34214
ENDEVCO SHOCK AMPLIFIER 2718A	HDL 26675
KEITHLEY 102B DECADE ISOLATION AMPLIFIER	HDL 22690
HP 6206B DC POWER SUPPLY	
GOULD (BRUSH) PAPER TAPE RECORDER	HDL 34109
BALLANTINE PRECISION CALIBRATOR	HDL 24891
HP ELECTRONIC COUNTER 5212A	HDL 25307
KEITHLEY 102B DECADE ISOLATION AMPLIFIER	DOFL 21384
KEITHLEY 102B DECADE ISOLATION AMPLIFIER	DOFL 16758

APPENDIX D. — ANALYSIS OF WEAR ON ARMING TIMERS, BY LAWRENCE P. McGINNIS

D-1. FIRST ANALYSIS — 18 FEBRUARY 1977

At the Harry Diamond Laboratories' (HDL) former site in Washington, D.C., the wear of the timers was measured by washing them in methanol, acetone, and, if necessary, in benzene. The wash liquids were passed through a weighed filter paper. The paper was placed in a constant humidity desiccator and then reweighed — the difference being the weight of the metal particles of wear from the timer. The filter paper was quite sensitive to the relative humidity (RH) of the room, and its weight changed greatly. The method was not workable.

Samples F-1 to F-8 were run as above. The metal collected was less than the weight change in the paper. The residue was checked by use of a microscope, but no conclusion was reached.

Sample F-9 was run by itself. On this sample, a blank was used. In addition, the paper (test and blank) was weighed several times over a week, and an average "empty" weight was taken. The run was made as above, and again the weight was taken over several days and averaged. By this method, a residue weight of 0.0076 g was achieved. This weight was, however, not considered satisfactory.

On sample F-10, the spent liquid was decanted slowly into another beaker, and the timer was washed with methyl alcohol, acetone, etc. The washings were set aside. All the residue was washed off with methyl alcohol into a weighed crucible; then the residue was dried and weighed. The washings were passed through a No. 42 filter paper that had been treated as in the F-9 sample so that very fine particles in suspension could be caught. The residue in the crucible was 0.0068 g and on the paper, 0.0028, making a total of 0.0096 g. At present, this is the best method to use.

Since other samples will most likely be processed in the same way, the condition of the new building at the HDL Adelphi, MD, site has been checked. The RH of the room is quite constant — about 20 percent. A large desiccator has been set up with H_2SO_4–H_2O so that at 24 C, the RH is 20 percent. This is close to the RH of the room.

D-2. ANALYSIS OF AS-DELIVERED TIMERS — 31 JANUARY 1978

Three "as-delivered" timers (F-38, F-48, F-58) were analyzed with the recommended procedures that had been used on other timers.

The purity of the timers was in question. They had been handled, examined, dismantled, and reassembled. They were not subjected to the TV test.

The impurity of the timers is shown in table D-1. The closer the net results are to zero, the purer are the timers. The gross loss is several milligrams. The total particles are about 1.5 mg, leaving a discrepancy of about 5.5 mg — here called "oil." The coarse particles are dirt. Examination with a magnifying glass shows some very fine pieces of fiber, as if from a brush. No metal particles were found. Organic dirt may be present, since after cleaning, the parts seemed a little brighter. This visual observation could not be checked. This fine dirt could have been carried over into the fine particles or, if soluble, burned off and counted as oil.

In reporting the results, blanks are not given—only the net results. The blanks are reported here to emphasize the result of improper handling of the timers. The blanks show the amount of impurities that are picked up from the reagents or from the improper handling of the solution in the analysis. The net results in this case, since these timers are considered to have arrived "pure," show the amount of impurities that the timers picked up in the prehandling (amount of contamination caused by human contact). Since the timers are washed in solvent with a brush (not scraped), it would not be harmful to have the visual inspection after the analysis. This would produce better results. Therefore, the recommended procedure is to analyze the timers without prior handling.

D-3. ONE METHOD OF ANALYSIS USED ON ARMING TIMERS

The arming timers are analyzed for metal particles to determine the amount of wear caused by the transportation vibration (TV) test. In this analysis,

Table D-1. Virgin Arming Timers (All weights in grams)

Analysis	Timer No.			
	F-38	F-48	F-58	Blank
Timer dried (70 C)	59.9836	60.1101	60.2251	
Timer washed in solvent	59.9778	60.0982	60.2168	
Gross loss	0.0058	0.0119	0.0083	
Beaker empty	12.6503	13.6220	13.6210	13.4508
Beaker and residue	12.6520	13.6242	13.6234	13.4515
Gross large particle	0.0017	0.0022	0.0024	0.0007
Blank	0.0007	0.0007	0.0007	
Large particles	0.0010	0.0015	0 0017	
Crucible empty	10.8659	10.3725	10.4391	10.8084
Crucible full	10.8671	10.3736	10.4403	10.8093
Gross fines	0.0012	0.0011	0.0012	0.0009
Blank	0.0009	0.0009	0.0009	
Fines	0.0003	0.0002	0.0003	
Large particles (above)	0.0010	0.0015	0.0017	
Total particles	0.0013	0.0017	0.0020	
Gross loss (above)	0.0058	0.0119	0.0083	
Total particles (above)	0.0013	0.0017	0.0020	
Difference "oil"	0.0045	0.0102	0.0063	

it is expected that general analytical care and techniques are to be used as outlined in any analytical test.[1,2]

The balance used is of the analytical type. It should be accurate enough to duplicate weighings to ± 0.1 mg. This balance should have a capacity of 200 g. Items to be weighed are not touched with the fingers – tongs are used, since fingerprints have weight.

The desiccator used should be airtight and charged with a good desiccant such as "Drierite."

All glass and porcelain used are to be "chemically clean" and free from scratches. They are to be washed in any good detergent, rinsed well with tap water, and then washed with a sulfuric acid dichromate solution[3] (use care because this solution is very corrosive and will attack clothing and skin). Rinse thoroughly (8 or 10 times) with tap water, then with distilled water, 3 times. (Rinsing many times with small quantities of distilled water is more efficient than fewer rinses with larger quantities). Turn upside down on a towel to drain. If in a hurry, rinse again in ethyl alcohol, drip dry, and place in an oven at 110 C. A beaker so treated should show no droplets when wet. If it does show droplets, it is not clean and must be cleaned again. The most convenient beaker sizes are 20, 250, and tall 400 ml. The 20-ml beakers are used as crucibles; hence they get special treatment.* They

[1] *William F. Hildebrand et al, Applied Inorganic Analysis, 2nd edition, revised by Lundell, Bright, et al, New York, Wiley and Sons (1953).*

[2] *Isaak M. Kolthoff and Ernest B. Sandell, Textbook of Quantitative Inorganic Analysis, McMillan Co. (1943)*

[3] *Handbook of Chemistry and Physics, Chemical Rubber Company, 49th edition (1968/69).*

**The best 20-ml beaker found by the author was by Corning (Catalog No. 1000, 20-ml Griffin).*

are to be marked so that the markings will not come off. (For example, their etched areas can be alternately marked with a No. 4 pencil and wiped off.) Place the beakers in a muffle oven at a temperature within the range of 250 to 300 C. When in the muffle, cover with a lid. After about an hour, remove and place in a desiccator to cool. When cool, weigh. Repeat until the weighings are within 0.1 mg of each other.

Coor's porcelain No. 0 is the best size crucible to use. The crucibles are to be washed in a detergent, then boiled in a 1:1 solution of hydrochloric acid, rinsed with tap water, then with distilled water, and fired over a Meker burner or in a muffle furnace at ~800 C for ~1 hour. Remove and place in a desiccator and let cool for about an hour. Repeat the heating and cooling until the weights are within 0.1 mg of each other.

The solvents called for are to be of American Chemical Society type — that is, the kind or quality used in analytical chemistry. The three used are methanol, benzene, and acetone; when called for, distilled water is used. There may be some criticism of the use of benzene since it is a health hazard. However, all the solvents should be used in a hood. When not in a hood, the beakers should be covered with Saran™ wrap held in place with a rubber band. With the hood and the Saran there should be no danger. The benzene should not be omitted, since it is an excellent grease dissolver and it can be obtained in a very pure form.

The timers are placed in a drying oven at a reasonably low temperature. The author used 70 C. This removes any moisture that may be present and, at the same time, does not decompose the oil on the bearings. After about 1 hour, the timers are transferred to the desiccator. Let cool 1 hour, then weigh. Repeat the heating and cooling until constant weight (0.2 mg) is obtained. Because a timer could damage the balance pan or knife edges if it is accidentally dropped (its weight is about 60 g), it should be handled by hand rather than with a pair of tongs. A finger cot or a piece of clean paper could be used in transferring the timer from the desiccator to the balance to avoid the addition of oil or perspiration from the fingers.

The timer can now be taken apart with the fingers. The lids can easily be taken off with a pocket knife. Because some of the small springs could easily be lost, it is best to take the timer apart in a box. Separate the parts carefully and place them in a 250-ml beaker. The parts are now covered with methanol and allowed to stand for 1 to 2 hours; the mixture should be stirred several times. Since this might be a convenient place to stop, the mixture could be left overnight, but the beaker should be covered with Saran.

The methanol, along with any loose particles, is drained into a tall 400-ml beaker. The dummy primer is not removed, as it will be harmed by the other solvents. Set the primer aside in a small beaker until the last weighing. To the beaker containing the parts, add enough benzene to cover. The beaker is then covered with wrap and placed in a shaker for 2 or 3 hours. It could then be left overnight. If a shaker is not available, the cleaning time can be lengthened to a day and the mixture stirred now and then. Since this is the main grease-dissolving procedure, it should not be rushed. When finished, remove the cover (in the hood) and pick each piece up with a heavy pair of tweezers or long-nosed pliers, and brush each piece with a small stiff brush. In these tests, a glue brush 7/8 by 3/4 in. was used. The parts should not be scraped. Each part is removed and placed on a watch glass. Then the benzene and any particles are transferred into the 400-ml beaker with the methanol, washing any sediment into the beaker with a stream of acetone from a wash bottle. All the parts are then transferred back to the 250-ml beaker with care, so as not to lose any of the small parts. The parts are then covered with acetone and set aside, but are stirred several times. The shaker can be omitted. As before, wash the acetone into the 400-ml beaker, washing any particles with a stream of acetone. Repeat the acetone wash two more times. After completing the washings, transfer the parts to an aluminum weighing dish, or other suitable container, along with the dummy primer, and place the container into the drying oven as before; then weigh the parts as before. Repeat the drying and weighing until constant weight is reached, as before. Remove the parts and weigh the dish with care. From the total weight, subtract the weight of the dish; this is the weight of the clean parts.

To another tall 400- or 500-ml beaker, place an amount of methanol, benzene, and acetone equal to the amount used in the sample. This is the blank. One blank is enough for any group of samples run together. This blank can be placed on the back of the steam bath, or low hot plate, with a loose cover. Cover closely enough to keep out dirt, but allow the solvent to be slowly evaporated. Do not allow the solvent of the samples to evaporate — keep them well covered with plastic wrap and a rubber band.

Allow the washings from the samples to stand for 6 hours or overnight (it is important that they not be moved). Make a device (as shown in fig. D-1) to suck up most of the solvent, leaving about 25 ml or so in the bottom. Add about 150 ml of acetone to the sample. Stir and again let sit 6 hours or overnight, and treat as before. Do this three times with the acetone. All the sucked-up washings from one sample are returned to the original beaker, covered loosely, and placed on the steam bath to slowly evaporate. Be sure to add an equal amount of acetone to the blank as was used in the washings, which are also allowed to evaporate slowly. Keep loosely covered to protect the residue.

The residue, along with the metal particles, is transferred to a weighed 20-ml beaker, with a stream of acetone. It is evaporated to dryness on the steam bath and kept clean. The beaker is replaced in an oven and heated at about 70 or 80 C for about 1 hour, desiccated, and weighed. Repeat the heating and cooling until the weights are within 0.2 mg or less of each other.

The beakers and the blank containing the solvent are placed on the back of the steam bath or on a low-temperature hot plate and evaporated almost to dryness. The residue is transferred to a weighed crucible with the aid of a fine jet of acetone from a wash bottle. The crucibles are evaporated to dryness on the low hot plate.

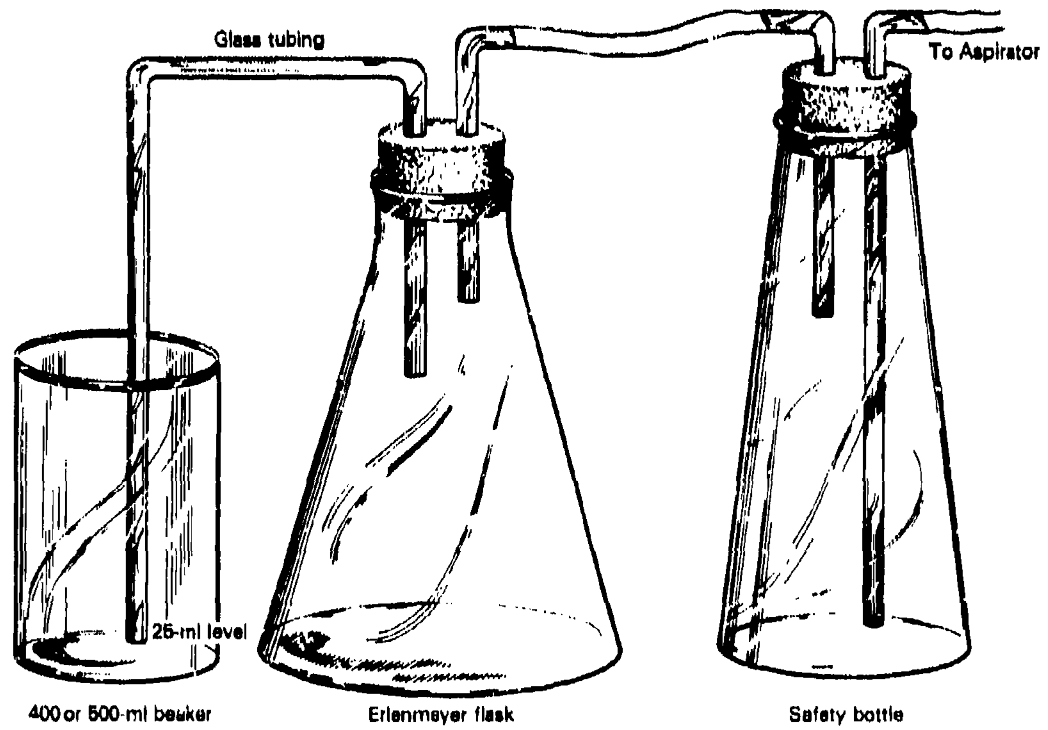


Figure D-1. Apparatus to separate solvent from metal particles.

To this point, the beakers have not been "policed," although this is necessary. However, the acetone seems to react with the soft-rubber-tipped glass rod used to dislodge particles from a beaker so as to quantitatively transfer them to the crucible. Therefore, the beakers are washed with a fine jet of distilled water from a wash bottle, collecting all the water in one beaker (of the same run, of course). With a few drops of water, police each beaker with the glass rod, and wash each beaker with a small amount of the water, combining the water into the crucible, a bit at a time, allowing the water to evaporate. When the crucible is dry, wipe the bottom with a clean cloth or a piece of filter paper. Place over a low flame and burn off the carbon. If a muffle is used, set the temperature at about 400 C with the lids ajar and the door partly open to allow air to get in. When the carbon is gone, close the door and raise the temperature to 600 C, no higher. If heating the crucible over a flame, raise the temperature until the crucible is a dull red. Rotate the crucible with a pair of tongs to remove any blackness, but do not heat too high. This is important, since much of the fine particles may be zinc, which can be vaporized easily. In fact, zinc boils off at 900 C completely. When finished, remove the crucible and place in a desiccator to cool. Weigh in about 1 hour. Repeat the heating and cooling until the weights are within 0.2 mg of each other.

The weight of the timers at the beginning of the analysis minus the weight of the timers in the clean state is the "Total Weight Loss."

The weight of the 20-ml beaker after the metal particles are collected minus the weight of the beaker in the initial state is the weight of the coarse particles. Label accordingly.

The weight of the fired crucible full minus the weight of the fired crucible empty is the uncorrected weight of the fine particles. This weight minus the blank, figured the same way, is the corrected weight of the fine particles. Label accordingly.

The weight of the coarse particles plus the weight of the fine particles is the weight of the total metal particles. This is a measure of the amount of wear caused by the TV test. Label this "Total." "Coarse," "Fines," and "Total" are all sub-titles under "Metal Particles Found." The "Total" subtracted from the "Total Weight Lost" is the amount of oil. Label this "Oil."

The figure given for the coarse particles is the most accurate and is 90 percent of the weight needed to measure the amount of wear caused by the TV test. The "Fines" account for 20 percent or less, but they do have the most error. The metal particles, for the most part, are composed of zinc and aluminum. If the fine particles are heated too high, there is the danger that some zinc is lost and some of the aluminum is changed to oxide. If the metal particles are not heated enough, there may be some carbon left. In addition, we assume that all the oil burns off. The organic part of the oil does, but some oils may have such additives as sodium salts, and these would be left. It can be seen that some of the errors are additive while others are in a negative application. However, since the fines are at the most only 10 percent of the total metal particles, the errors may neutralize each other. Further correction is not advised. The main consideration is to have a good value to act as a measure of comparison between samples.

As can be seen, the oil is found by difference. All the errors in any part of the analysis will fall on this section. For example, any of the alkali salts, such as sodium, that may have been in the oil will be found and counted as fine particles. A knowledge of the original oil used might help clear this up somewhat but is probably not necessary.

APPENDIX E. — S&A VIBRATION TEST DATA RECORDS

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TABLE E-1, S&A VIBRATION TEST DATA, April 13, 14, 1977

EVENT	Start Time				End Time				Duration	Tape Recorder Channel	Tape Reel No.	
	D	H	M	S	D	H	M	S	(Min)(s)			
Calibration	102	11	13	23	102	13	32	53	5-3	2-7	1	
Run-1 Test-1	102	14	9	01	102	14	38	54	30	2-7	1	
Calibration	103	9	10	41	103	9	20	40	1-41	2-7	1	
Run-1 Test-2	103	9	24	15	103	9	54	01	30	2-7	1	
Calibration	103	10	10	12	103	10	20	51	3-37	2-7	2	
Run-1 Test-3	103	10	40	20	103	11	10	20	30	2-7	2	
Calibration	104	11	16	09	104	11	40	58	4-59	2-7	2	
Run-2 Test-1	104	13	38	40	104	14	17*	17	30	2-7	2	Bad Reading
Calibration	104	14	52	15	104	15	02	25	3-29	2-7	3	
Run-2 Test-2	104	15	03	30	104	15	33	30	30	2-7	3	
Run-2 Test-3	104	15	41	30	104	16	12	16	30	2-7	3	
Channel No:	1	2	3	4	5	6	7					
Data	IRIG B	Freq	Cont. Acc	Acc-Z	Acc-Y	Acc-X	Gage					

Run Number indicates position of accelerometer on S&A device   See Figure 1, body of report.

Run # 1: Accelerometer opposite (180°) strain gage

Run # 2: Accelerometer adjacent (90°) strain gage

Test Number indicates position of device on shaker table   See Figure 1, body of report.

Test-1: Device on top of shaker, Z-component vertical

Test-2: Device on side of shaker, X-component vertical

Test-3: Device on side of shaker, Y-component vertical

TABLE E-2. ACCELEROMETER TEST DATA MAY 12, 1977

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
Calibration												
Strain gage										7-FM		
100 (MV RMS)	102	11	13	23	102	11	13	34	11	7-FM	1	
200	102	11	13	34	102	11	13	34	0.35	7-FM	1	
300	102	11	13	34	102	11	13	40	6	7-FM	1	
X Channel	Tri-Axial Accelerometer											
300 (MV RMS)	102	11	14	47	102	11	14	00	13	6-FM	1	
200	102	11	14	00	102	11	14	04	4	6-FM	1	
100	102	11	14	04	102	11	14	11	7	6-FM	1	
Y Channel	Tri-Axial Accelerometer											
500 (MV RMS)	102	11	17	23	102	11	17	35	12	5-FM	1	
400	102	11	17	35	102	11	17	38	3	5-FM	1	
300	—	—	17	38	—	—	17	42	4	5-FM	1	
200	—	—	17	42	—	—	17	46	4	5-FM	1	
100	—	—	17	46	—	—	17	49	3	5-FM	1	
Z Channel	Tri-Axial Accelerometer											
1000 (MV RMS)	102	11	18	42	102	11	18	57	15	4-FM	1	
800	—	—	18	57	—	—	19	03	5	4-FM	1	
600	—	—	19	03	—	—	19	07	4	4-FM	1	
400	—	—	19	07	—	—	19	11	4	4-FM	1	
200	—	—	19	11	—	—	19	16	5	4-FM	1	
100	—	—	19	16	—	—	19	21	5	4-FM	1	

TABLE E-3, S&A TEST DATA, May 12, 1977

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
Calibration Control Accel. Channel												
500 (mV RMS)	102	11	21	22	102	11	21	32	10	3-FM	1	
400	—	—	21	32	—	—	21	35	3	3-FM	1	
300	—	—	21	35	—	—	21	38	3	3-FM	1	
200	—	—	21	38	—	—	21	41	3	3-FM	1	
100	—	—	21	41	—	—	21	45	4	3-FM	1	
Frequency Channel												
500Hz/1V dc	102	13	30	00	102	13	30	31	31	2-FM	1	
400Hz/.8V dc	—	—	30	31	—	—	31	00	29	2-FM	1	
300Hz/.6V dc	—	—	31	00	—	—	31	21	21	2-FM	1	
200 Hz/.4V dc	—	—	31	21	—	—	31	51	30	2-FM	1	
100 Hz/.2V dc	—	—	31	51	—	—	32	25	36	2-FM	1	
2 Hz/≈ OV dc	—	—	32	25	—	—	32	53	28	2-FM	1	
RUN # 1 TEST 1	102	14	9	01	102	14	38	54	≈ 30 min	2-7	1	
Calibration												
Z CH. 500 (mV RMS)	103	9	10	41	103	9	11	05	24	4-FM	1	
Y CH. 500 (mV RMS)	103	9	13	10	103	9	13	26	16	5-FM	1	
X CH. 500 (mV RMS)	103	9	15	01	103	9	15	17	16	6-FM	1	
300 mV RMS Strain Gage Channel	103	9	18	57	103	9	19	10	13	7-FM	1	
Frequency Channel 500Hz/1V dc	103	9	20	08	103	9	20	40	32	2-FM	1	
RUN # 1 TEST 2	103	9	24	15	103	9	54	01	≈30 min	2-7	1	Cont. Acc. Ch. Bad
Calibration												
Frequency Channel												
500 Hz/1000 mV dc	103	10	10	12	103	10	10	32	20	2-FM	2	
400Hz/800 mV dc	103	10	10	51	103	10	11	11	20	2-FM	2	
300 Hz/600 mV dc	103	10	11	13	103	11	11	40	27	2-FM	2	
200 Hz/400 mV dc	103	10	11	40	103	11	12	02	22	2-FM	2	
100 Hz/200 mV dc	103	10	12	02	103	11	12	26	24	2-FM	2	

TABLE E-3, S&A TEST DATA, May 12, 1977 (Cont'd)

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
Z Channel	Tri-Axial Accelerometer											Cont.Acc. Ch. Bad
500 (mV RMS)	103	10	16	5	103	10	16	15	10	4-FM	2	
400	103	10	16	15	103	10	16	21	6	4-FM	2	
300	103	10	16	22	103	10	16	27	5	4-FM	2	
200	103	10	16	27	103	10	16	31	4	4-FM	2	
100	103	10	16	31	103	10	16	34	3	4-FM	2	
Y Channel	Tri-Axial Accelerometer											
500 (mV RMS)	103	10	17	39	103	10	17	44	5	5-FM	2	
400	103	10	17	44	103	10	17	48	4	5-FM	2	
300	103	10	17	48	103	10	17	52	4	5-FM	2	
200	103	10	17	52	103	10	17	55	3	5-FM	2	
100	103	10	17	55	103	10	17	58	3	5-FM	2	
X Channel	Tri-Axial Accelerometer											
500 (mV RMS)	103	10	18	55	103	10	19	08	13	6-FM	2	
400	103	10	19	08	103	10	19	09	1	6-FM	2	
300	103	10	19	09	103	10	19	12	3	6-FM	2	
200	103	10	19	12	103	10	19	15	3	6-FM	2	
100	103	10	19	15	103	10	19	18	3	6-FM	2	
Calibration												
Strain Gage Channel												
500 (mV RMS)	103	10	20	21	103	10	20	29	8	7-FM	2	
400	—	—	20	29	—	—	20	35	6	7-FM	2	
300	—	—	20	35	—	—	20	41	6	7-FM	2	
200	—	—	20	41	—	—	20	46	5	7-FM	2	
100	—	—	20	46	—	—	20	51	5	7-FM	2	
RUN # 1 TEST 3	103	10	40	20	103	11	10	20	≈ 30 min.	2-7	2	
Calibration												
Strain Gage Channel												
10 (mV RMS)	104	11	16	09	104	11	16	15	6	7-FM	2	
20	—	—	16	15	—	—	16	22	7	7-FM	2	
30	—	—	16	22	—	—	16	30	8	7-FM	2	

TABLE E-3, S&A TEST DATA, May 12, 1977 (Cont'd)

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
40	—	—	16	30	—	—	16	58	28	7-FM	2	
50	—	—	16	58	—	—	17	09	11	7-FM	2	
100	—	—	17	09	—	—	17	24	15	7-FM	2	
300	—	—	17	42	—	—	17	56	14	7-FM	2	
400	—	—	17	56	—	—	18	04	8	7-FM	2	
500	—	—	18	04	—	—	18	10	6	7-FM	2	
600	—	—	18	10	—	—	18	15	5	7-FM	2	
700	—	—	18	15	—	—	18	19	4	7-FM	2	
800	—	—	18	19	—	—	18	23	4	7-FM	2	
900	—	—	18	23	—	—	18	28	5	7-FM	2	
1000	—	—	18	28	—	—	18	40	12	7-FM	2	
Calibration												
X Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	11	25	45	104	11	25	50	5	6-FM	2	
20	—	—	25	50	—	—	25	53	3	6-FM	2	
30	—	—	25	53	—	—	25	56	3	6-FM	2	
40	—	—	25	56	—	—	25	59	3	6-FM	2	
50	—	—	25	59	—	—	26	02	3	6-FM	2	
60	—	—	26	02	—	—	26	05	3	6-FM	2	
70	—	—	26	05	—	—	26	08	3	6-FM	2	
80	—	—	26	08	—	—	26	11	3	6-FM	2	
90	—	—	26	11	—	—	26	15	4	6-FM	2	
100	—	—	26	15	—	—	26	25	10	6-FM	2	
200	—	—	26	28	—	—	26	32	4	6-FM	2	
300	—	—	26	32	—	—	26	35	3	6-FM	2	
400	—	—	26	35	—	—	26	37	2	6-FM	2	
500	—	—	26	37	—	—	26	40	3	6-FM	2	
600	—	—	26	40	—	—	26	41	1	6-FM	2	
700	—	—	26	41	—	—	26	43	2	6-FM	2	
800	—	—	26	43	—	—	26	45	2	6-FM	2	
900	—	—	26	45	—	—	26	47	2	6-FM	2	
1000	—	—	26	47	—	—	26	50	3	6-FM	2	

TABLE E-3, S&A TEST DATA, May 12, 1977 (Cont'd)

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
Calibration												
Y Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	11	29	09	104	11	29	11	2	5-FM	2	
20	—	—	29	11	—	—	29	12	1	5-FM	2	
30	—	—	29	12	—	—	29	14	2	5-FM	2	
40	—	—	29	14	—	—	29	16	2	5-FM	2	
50	—	—	29	16	—	—	29	18	2	5-FM	2	
60	—	—	29	18	—	—	29	20	2	5-FM	2	
70	—	—	29	20	—	—	29	22	2	5-FM	2	
80	—	—	29	22	—	—	29	24	2	5-FM	2	
90	—	—	29	24	—	—	29	26	2	5-FM	2	
100	—	—	29	26	—	—	29	28	2	5-FM	2	
200	—	—	29	30	—	—	29	32	2	5-FM	2	
300	—	—	29	32	—	—	29	34	2	5-FM	2	
400	—	—	29	34	—	—	29	36	2	5-FM	2	
500	—	—	29	36	—	—	29	38	2	5-FM	2	
600	—	—	29	38	—	—	29	40	2	5-FM	2	
700	—	—	29	40	—	—	29	42	2	5-FM	2	
800	—	—	29	42	—	—	29	44	2	5-FM	2	
900	—	—	29	44	—	—	29	46	2	5-FM	2	
1000	—	—	29	46	—	—	29	50	4	5-FM	2	
Calibration												
Z Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	11	38	41	104	11	38	44	3	4-FM	2	
20	—	—	38	44	—	—	38	45	1	4-FM	2	
30	—	—	38	45	—	—	38	47	2	4-FM	2	
40	—	—	38	47	—	—	38	49	2	4-FM	2	
50	—	—	38	49	—	—	38	51	2	4-FM	2	
60	—	—	38	51	—	—	38	53	2	4-FM	2	
70	—	—	38	53	—	—	38	55	2	4-FM	2	
80	—	—	38	55	—	—	38	57	2	4-FM	2	
90	—	—	38	57	—	—	38	59	2	4-FM	2	
100	—	—	38	59	—	—	39	01	2	4-FM	2	
200	—	—	39	01	—	—	39	03	2	4-FM	2	
300	—	—	39	04	—	—	39	06	2	4-FM	2	

TABLE E-3, S&A TEST DATA, May 12, 1977 (Cont'd)

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
400	—	—	39	06	—	—	39	08	2	4-FM	2	
500	—	—	39	08	—	—	39	10	2	4-FM	2	
600	—	—	39	10	—	—	39	12	2	4-FM	2	
700	—	—	39	12	—	—	39	14	2	4-FM	2	
800	—	—	39	14	—	—	39	16	2	4-FM	2	
900	—	—	39	16	—	—	39	18	2	4-FM	2	
1000	—	—	39	18	—	—	39	22	4	4-FM	2	
Calibration												
Frequency Channel												
≈0Hz/≈0V dc	104	11	40	25	104	11	40	35	10	2-FM	2	
500 Hz/IV dc	104	11	40	43	104	11	40	58	15	2-FM	2	
RUN # 2												
TEST 1	104	13	38	40	104	14*	17	17	≈30 min	2-7	2	*bad reading from *T.C.G.*
Calibration												
Strain Gage Channel												
10 (mV RMS)	104	14	52	15	104	14	52	17	2	7-FM	3	
20	—	—	52	17	—	—	52	19	2	7-FM	3	
30	—	—	52	19	—	—	52	21	2	7-FM	3	
40	—	—	52	21	—	—	52	23	2	7-FM	3	
50	—	—	52	23	—	—	52	25	2	7-FM	3	
60	—	—	52	25	—	—	52	27	2	7-FM	3	
70	—	—	52	27	—	—	52	29	2	7-FM	3	
80	—	—	52	29	—	—	52	31	2	7-FM	3	
90	—	—	52	31	—	—	52	33	2	7-FM	3	
100	—	—	52	33	—	—	52	35	2	7-FM	3	
200	—	—	52	36	—	—	52	38	2	7-FM	3	
300	—	—	52	38	—	—	52	40	2	7-FM	3	
400	—	—	52	40	—	—	52	42	2	7-FM	3	
500	—	—	52	42	—	—	52	44	2	7-FM	3	
600	—	—	52	44	—	—	52	45	1	7-FM	3	
700	—	—	52	45	—	—	52	46	1	7-FM	3	
800	—	—	52	46	—	—	52	47	1	7-FM	3	
900	—	—	52	47	—	—	52	49	2	7-FM	3	
1000	—	—	52	49	—	—	52	53	4	7-FM	3	

TABLE E-3, S&A TEST DATA, May 12, 1977 (Cont'd)

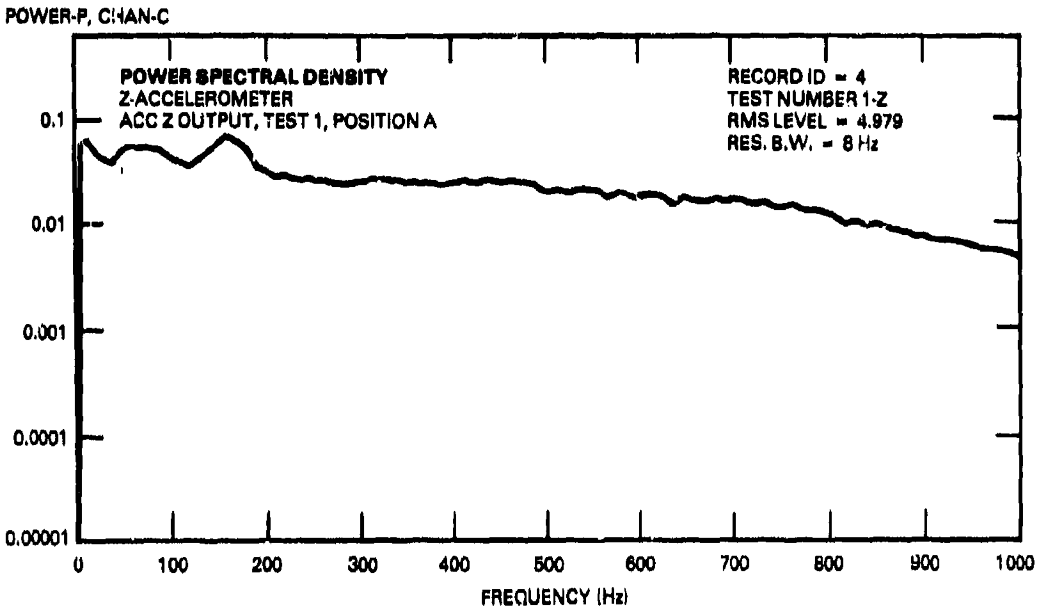
EVENT	Start Time D	Start Time H	Start Time M	Start Time S	End Time D	End Time H	End Time M	End Time S	Duration (s)	Recorder Channel No. Mode	Tape Reel No.	Notes
Calibration												
X Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	14	54	03	104	14	54	05	2	6-FM	3	
20	—	—	54	05	—	—	54	07	2	6-FM	3	
30	—	—	54	07	—	—	54	09	2	6-FM	3	
40	—	—	54	09	—	—	54	11	2	6-FM	3	
50	—	—	54	11	—	—	54	13	2	6-FM	3	
60	—	—	54	13	—	—	54	15	2	6-FM	3	
70	—	—	54	15	—	—	54	17	2	6-FM	3	
80	—	—	54	17	—	—	54	19	2	6-FM	3	
90	—	—	54	19	—	—	54	21	2	6-FM	3	
100	—	—	54	21	—	—	54	23	2	6-FM	3	
200	—	—	54	24	—	—	54	28	4	6-FM	3	
300	—	—	54	28	—	—	54	31	3	6-FM	3	
400	—	—	54	31	—	—	54	34	3	6-FM	3	
500	—	—	54	34	—	—	54	37	3	6-FM	3	
600	—	—	54	37	—	—	54	39	2	6-FM	3	
700	—	—	54	39	—	—	54	41	2	6-FM	3	
800	—	—	54	41	—	—	54	43	2	6-FM	3	
900	—	—	54	43	—	—	54	45	2	6-FM	3	
1000	—	—	54	45	—	—	54	48	3	6-FM	3	
Calibration												
Y Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	14	57	33	104	14	57	36	3	5-FM	3	
20	—	—	57	36	—	—	57	48	12	5-FM	3	
30	—	—	57	48	—	—	57	55	7	5-FM	3	
40	—	—	57	55	—	—	57	58	3	5-FM	3	
50	—	—	57	58	—	—	58	00	2	5-FM	3	
60	—	—	58	00	—	—	58	02	2	5-FM	3	
70	—	—	58	02	—	—	58	04	2	5-FM	3	
80	—	—	58	04	—	—	58	06	2	5-FM	3	
90	—	—	58	06	—	—	58	08	2	5-FM	3	
100	—	—	58	08	—	—	58	12	4	5-FM	3	
200	—	—	58	13	—	—	58	16	3	5-FM	3	
300	—	—	58	16	—	—	58	19	3	5-FM	3	
400	—	—	58	19	—	—	58	22	3	5-FM	3	

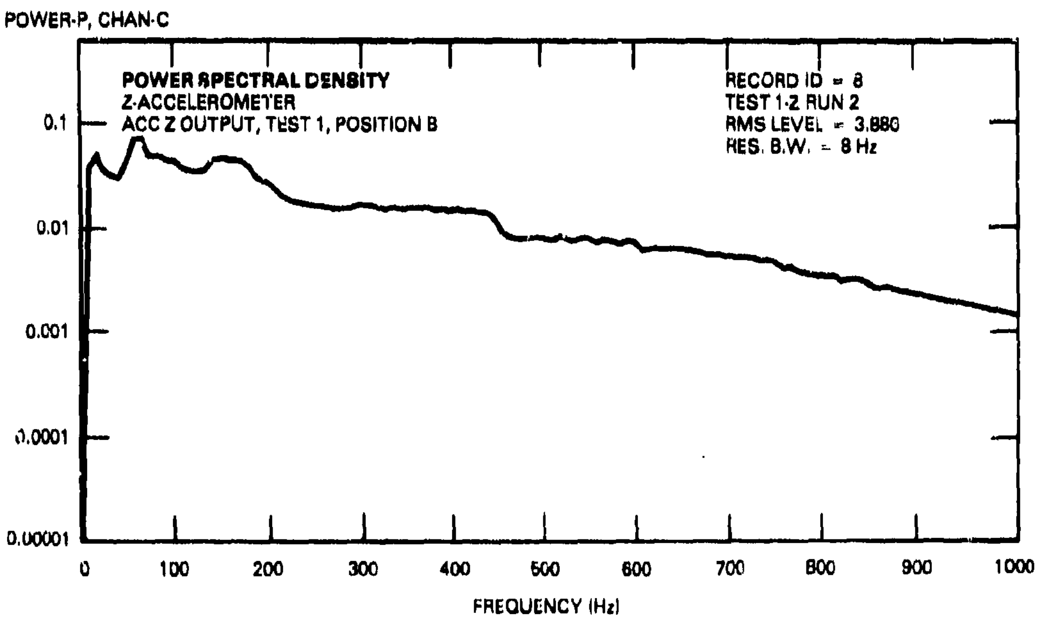
TABLE E-3. S&A TEST DATA MAY 12, 1977 (Cont'd)

EVENT	Start Time				End Time				Duration	Recorder Channel No. Mode	Tape Reel No.	Notes
	D	H	M	S	D	H	M	S	(s)			
500	—	—	58	22	—	—	58	24	2	5-FM	3	
600	—	—	58	24	—	—	58	26	2	5-FM	3	
700	—	—	58	26	—	—	58	28	2	5-FM	3	
800	—	—	58	28	—	—	58	30	2	5-FM	3	
900	—	—	58	30	—	—	58	32	2	5-FM	3	
1000	—	—	58	32	—	—	58	39	7	5-FM	3	
Calibration Z Channel	Tri-Axial Accelerometer											
10 (mV RMS)	104	15	0	00	104	15	0	02	2	4-FM	3	
20	—	—	0	02	—	—	0	04	2	4-FM	3	
30	—	—	0	04	—	—	0	06	2	4-FM	3	
40	—	—	0	06	—	—	0	08	2	4-FM	3	
50	—	—	0	08	—	—	0	10	2	4-FM	3	
60	—	—	0	10	—	—	0	12	2	4-FM	3	
70	—	—	0	12	—	—	0	14	2	4-FM	3	
80	—	—	0	14	—	—	0	16	2	4-FM	3	
90	—	—	0	16	—	—	0	18	2	4-FM	3	
100	—	—	0	18	—	—	0	20	2	4-FM	3	
200	—	—	0	21	—	—	0	23	2	4-FM	3	
300	—	—	0	23	—	—	0	25	2	4-FM	3	
400	—	—	0	25	—	—	0	27	2	4-FM	3	
500	—	—	0	27	—	—	0	29	2	4-FM	3	
600	—	—	0	29	—	—	0	31	2	4-FM	3	
700	—	—	0	31	—	—	0	34	3	4-FM	3	
800	—	—	0	34	—	—	0	36	2	4-FM	3	
900	—	—	0	36	—	—	0	38	2	4-FM	3	
1000	—	—	0	38	—	—	0	44	6	4-FM	3	
Calibration Frequency Channel												
≈0Hz/≈0V dc	104	15	01	57	104	15	02	07	10	2-FM	3	
500Hz/1V dc	104	15	02	15	104	15	02	25	10	2-FM	3	
RUN – 2												
TEST 2	104	15	03	30	104	15	33	30	≈30 min	2-7	3	
TEST 3	104	15	41	30	104	16	12	16	≈30 min	2-7	3	

APPENDIX F. — SPECTRAL DATA ANALYSIS RECORDS

This appendix presents the results of an analysis of raw data collected on the S&A module in various test configurations. Refer to individual test records (app E) for test configuration and identification (raw data have not been included).





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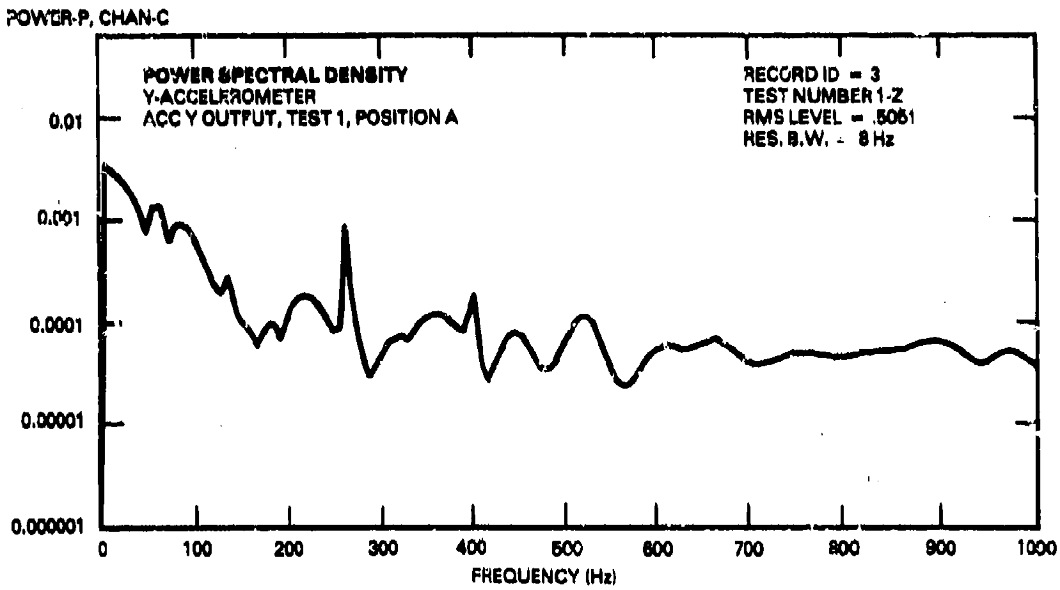
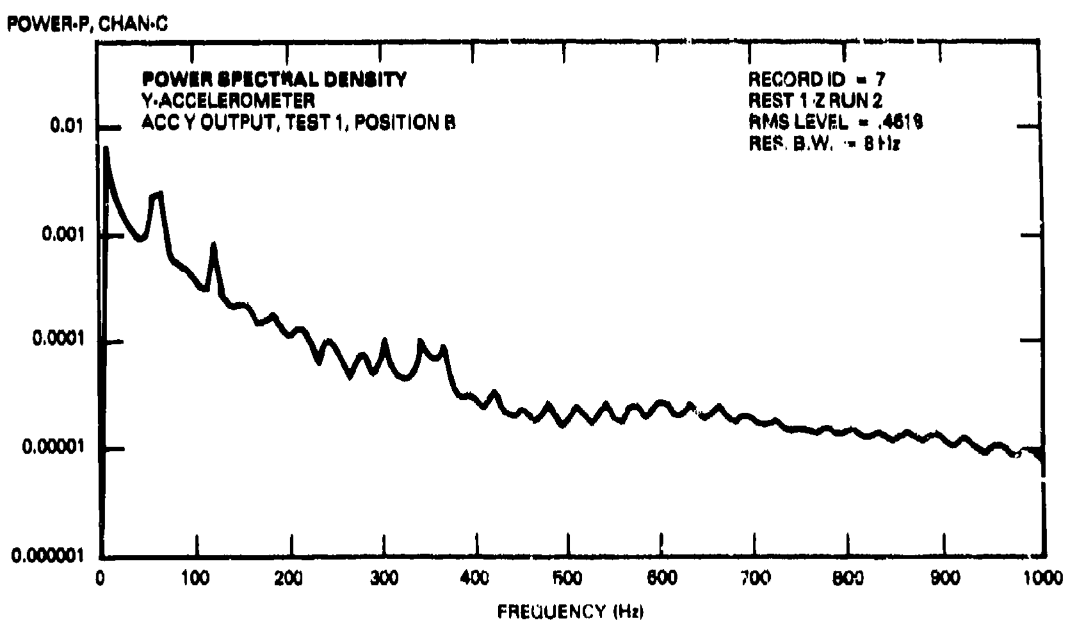
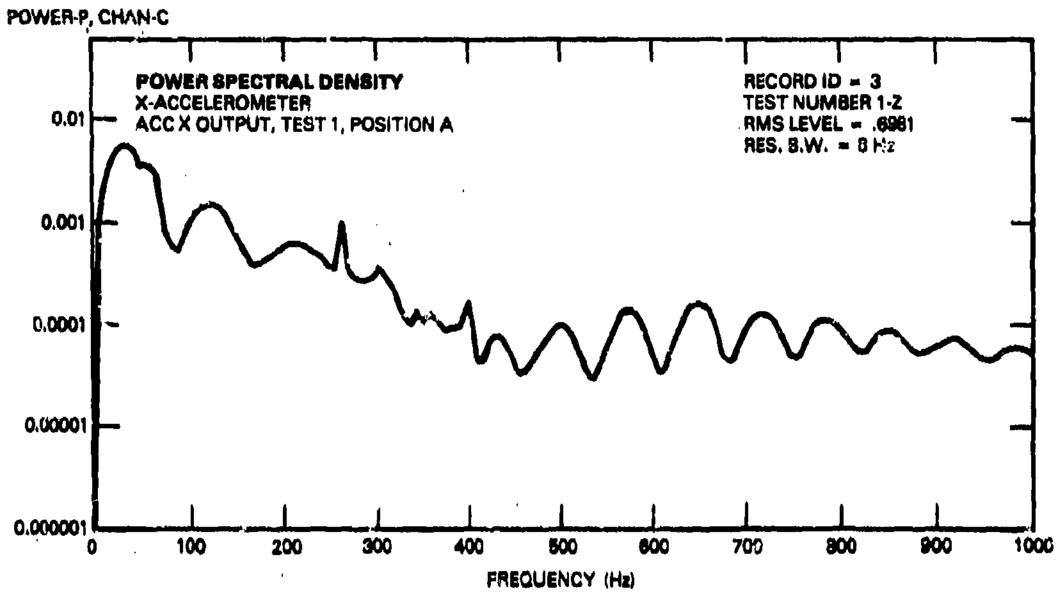
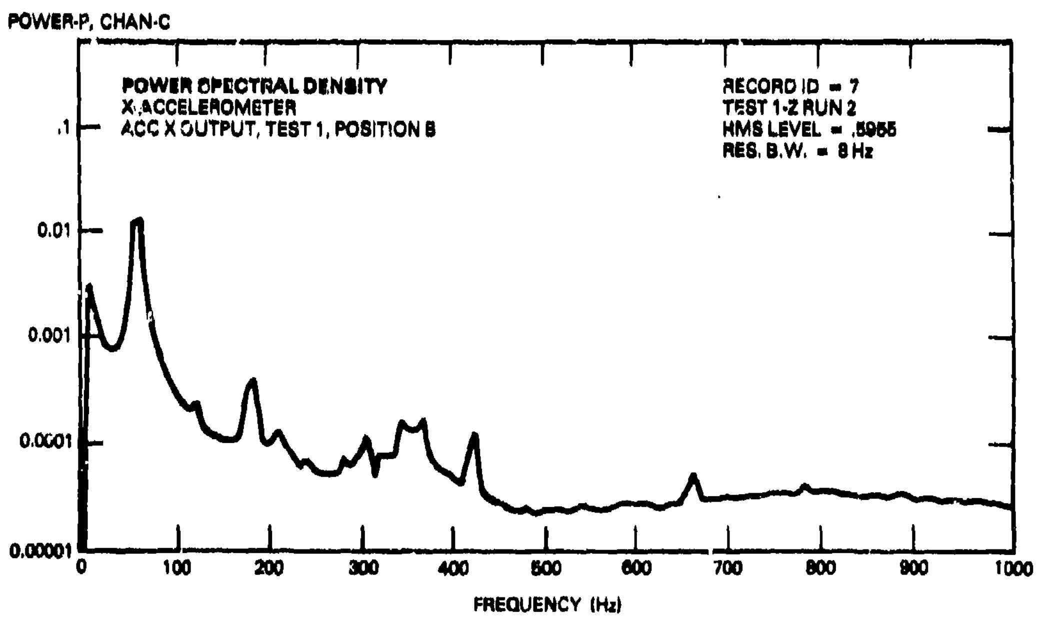
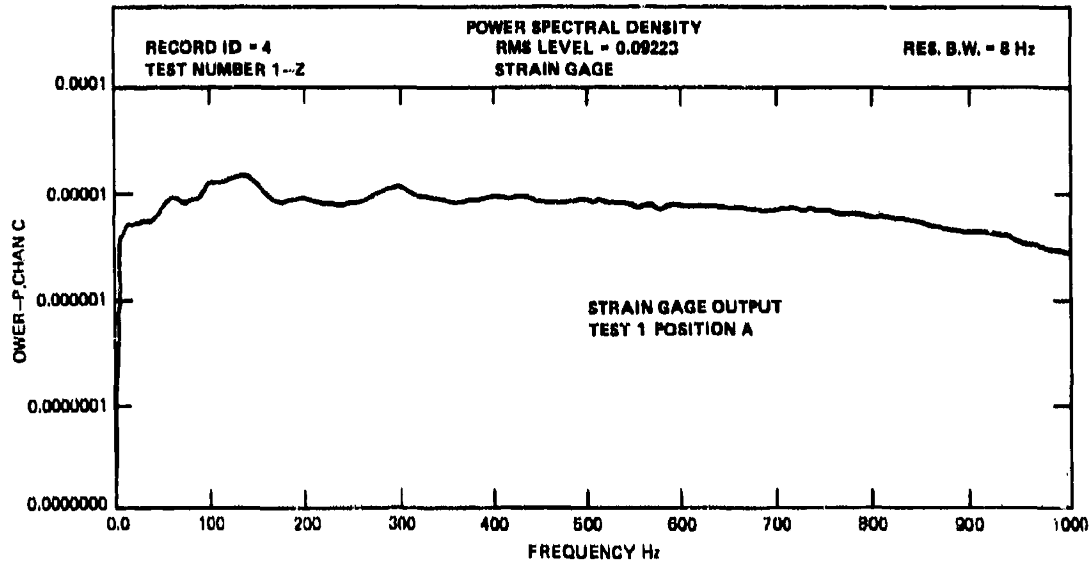
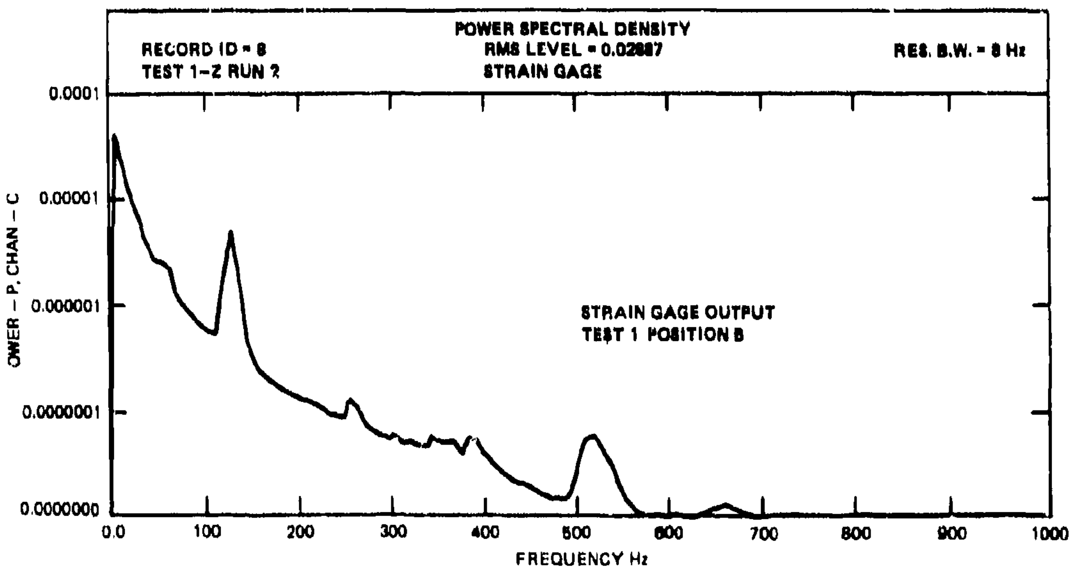

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Y-ACCELEROMETER
ACC Y OUTPUT, TEST 1, POSITION A
RECORD ID = 3
TEST NUMBER 1-Z
RMS LEVEL = .5051
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

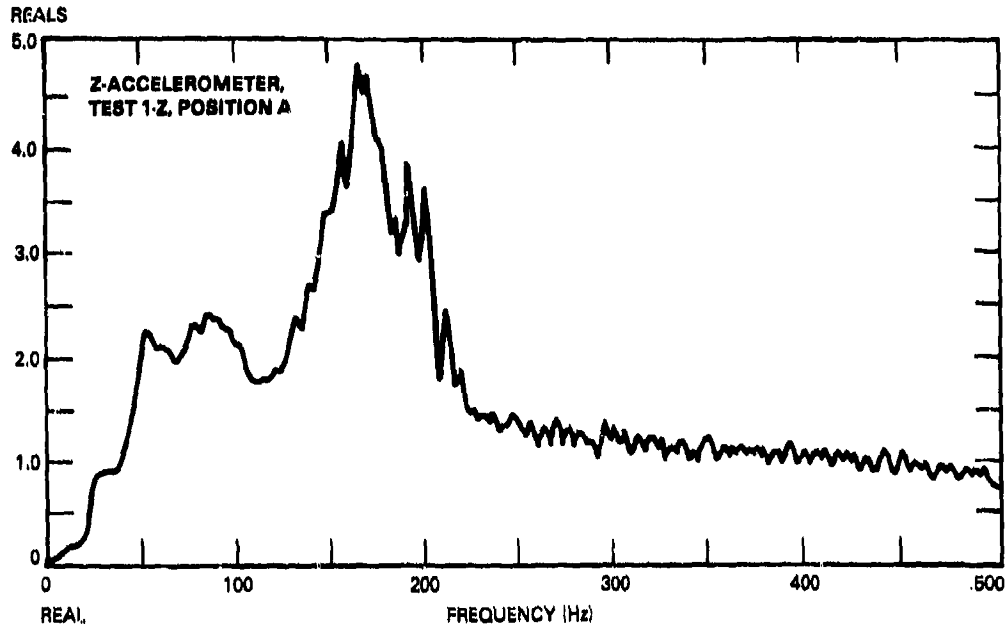

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Y-ACCELEROMETER
ACC Y OUTPUT, TEST 1, POSITION B
RECORD ID = 7
REST 1-Z RUN 2
RMS LEVEL = .4619
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

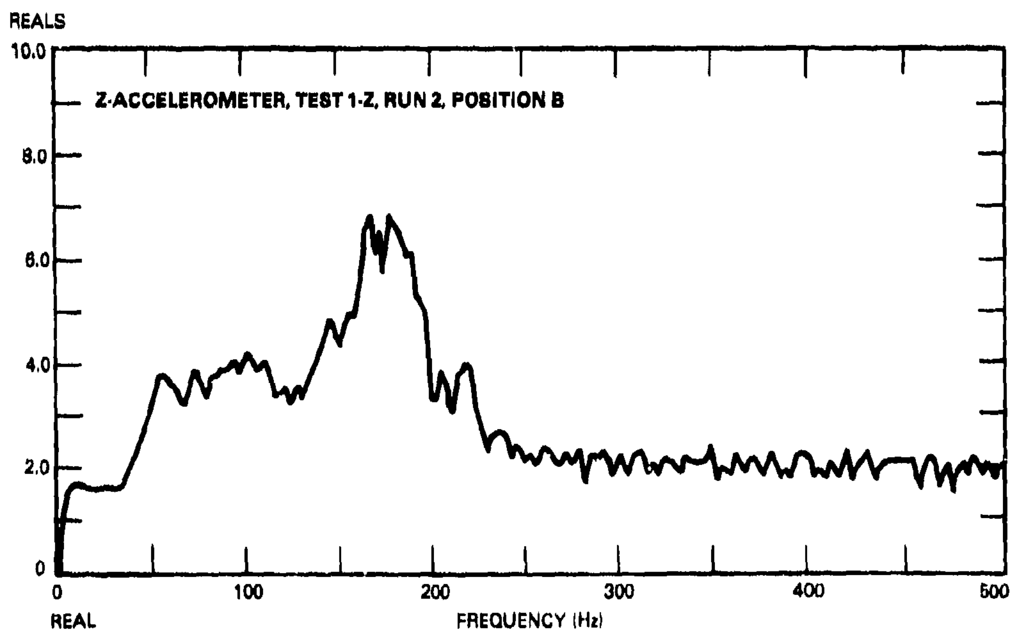

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
X-ACCELEROMETER
ACC X OUTPUT, TEST 1, POSITION A
RECORD ID = 3
TEST NUMBER 1-Z
RMS LEVEL = .6981
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

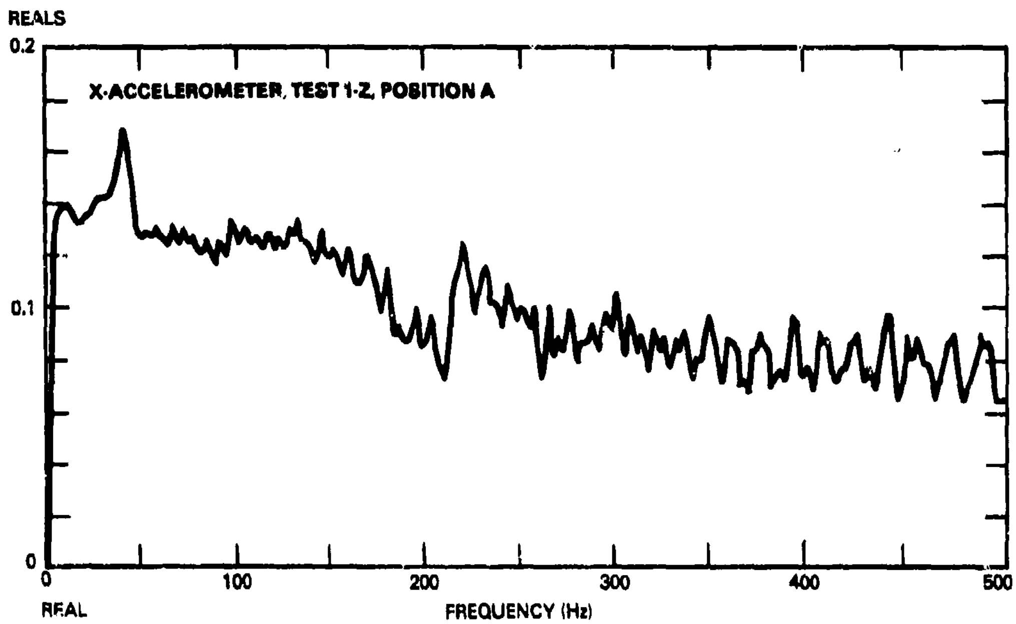

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
X-ACCELEROMETER
ACC X OUTPUT, TEST 1, POSITION B
RECORD ID = 7
TEST 1-Z RUN 2
RMS LEVEL = .5955
RES. B.W. = 8 Hz
.1
0.01
0.001
0.0001
0.00001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

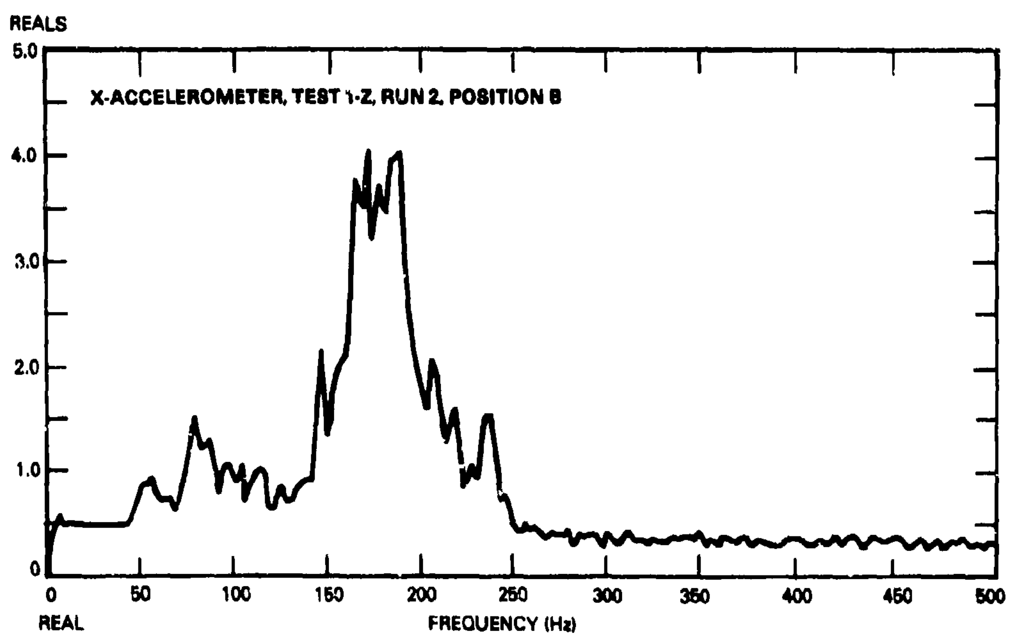

POWER SPECTRAL DENSITY
RECORD ID = 4
RMS LEVEL = 0.09223
RES. B.W. = 8 Hz
TEST NUMBER 1--Z
STRAIN GAGE
0.0001
0.00001
0.000001
0.0000001
0.0000000
OWER—P,CHAN C
STRAIN GAGE OUTPUT
TEST 1 POSITION A
0.0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY Hz

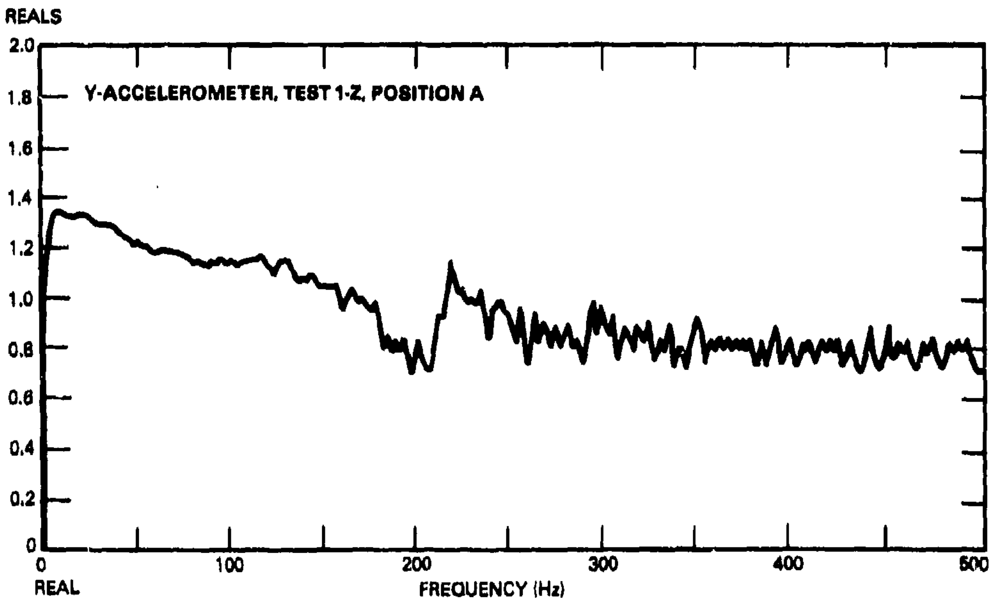

POWER SPECTRAL DENSITY
RECORD ID = 8
RMS LEVEL = 0.02887
RES. B.W. = 8 Hz
TEST 1-Z RUN 2
STRAIN GAGE
0.0001
0.00001
0.000001
0.0000001
0.0000000
OWER — P, CHAN — C
STRAIN GAGE OUTPUT
TEST 1 POSITION B
0.0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY Hz

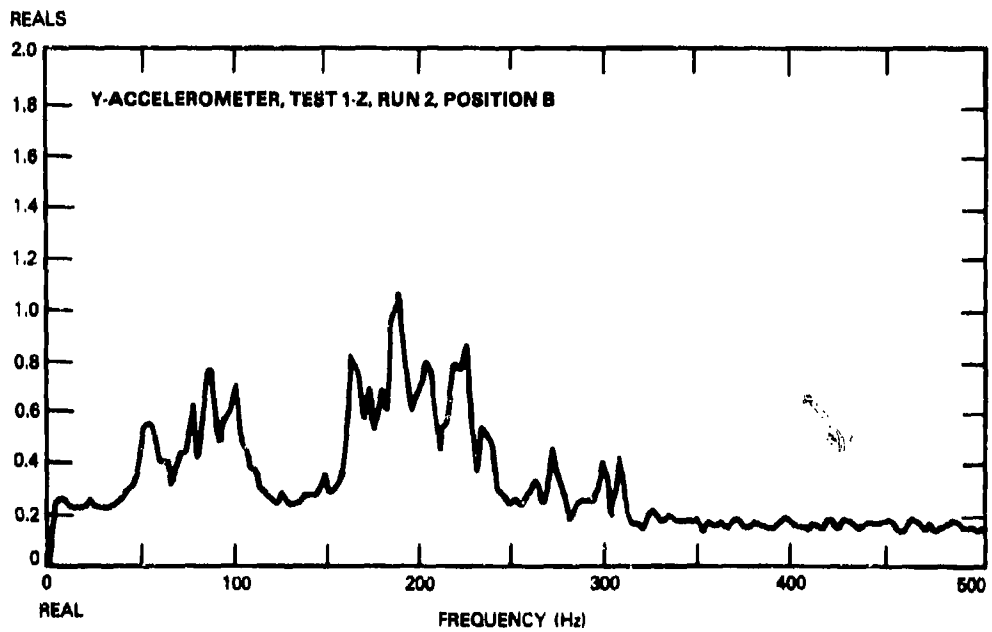

REALS
5.0
4.0
3.0
2.0
1.0
0
Z-ACCELEROMETER,
TEST 1-Z, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

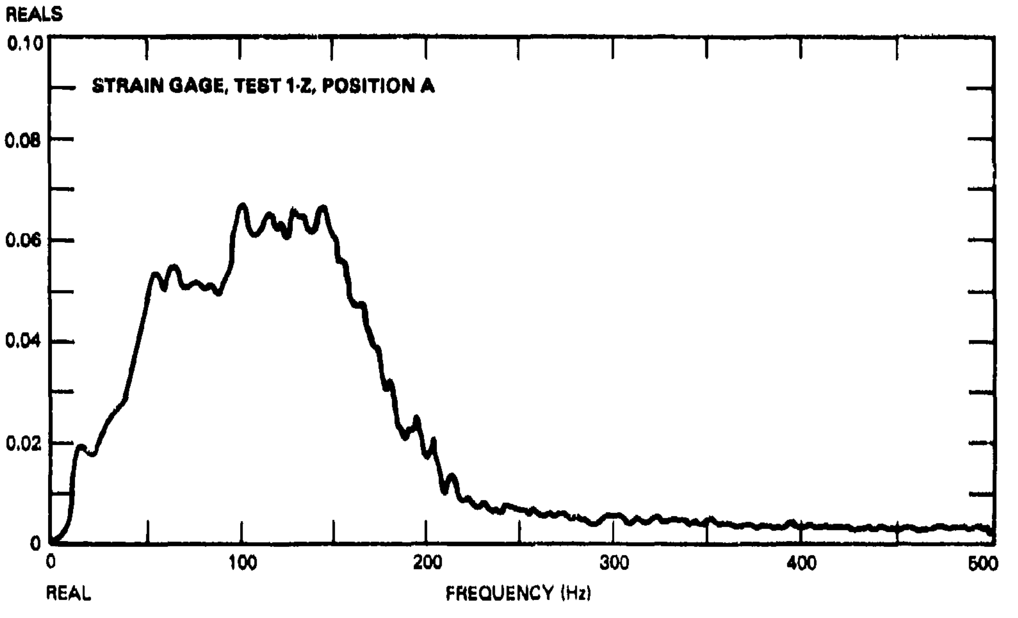

REALS
10.0
8.0
6.0
4.0
2.0
0
Z-ACCELEROMETER, TEST 1-Z, RUN 2, POSITION B
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

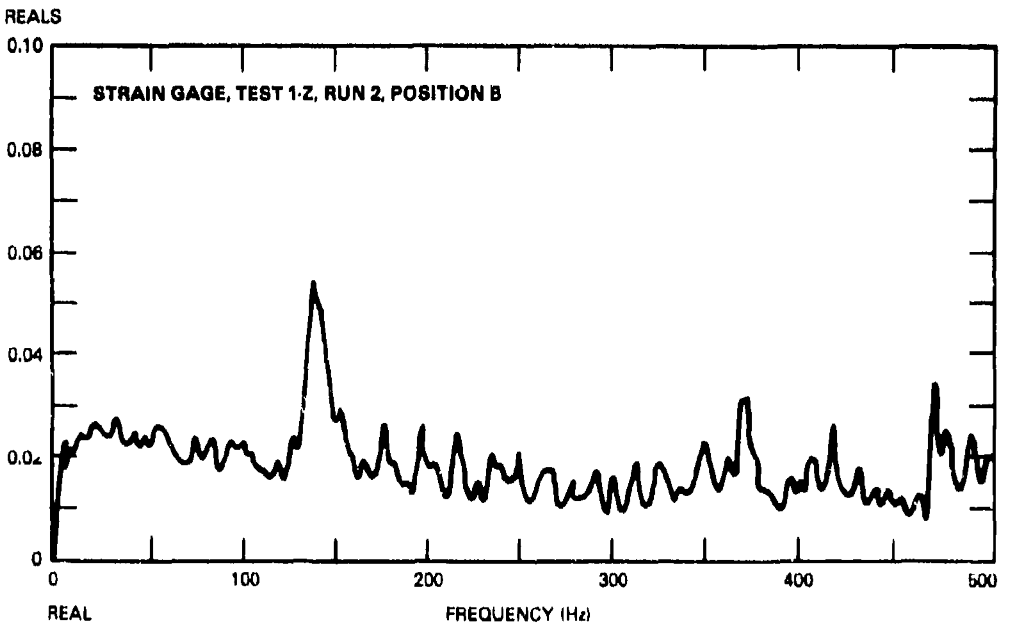

REALS
0.2
X-ACCELEROMETER, TEST 1-Z, POSITION A
0.1
0
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

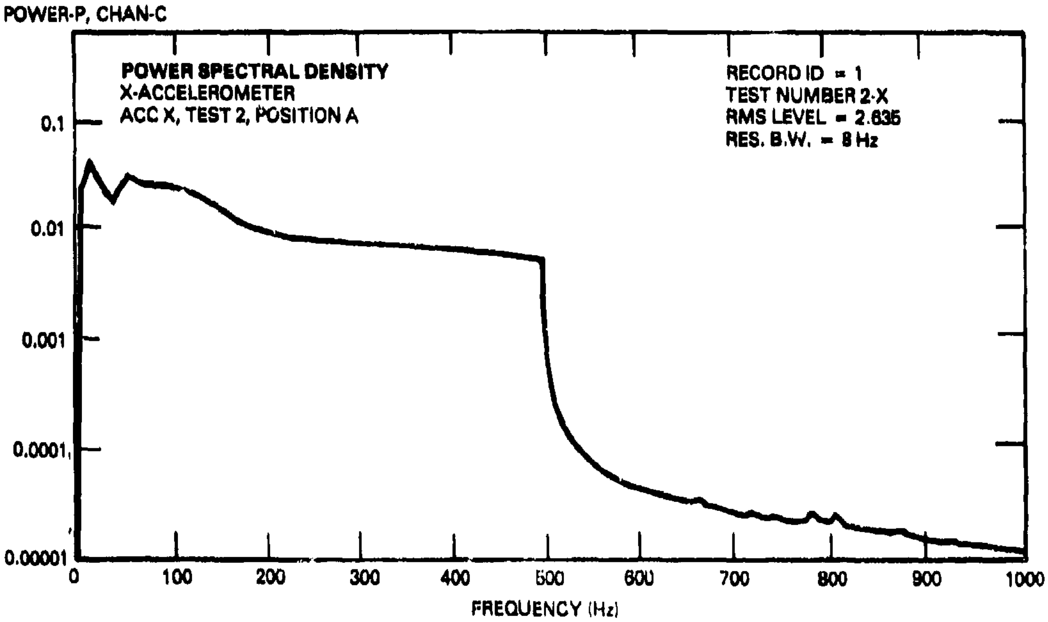

REALS
5.0
X-ACCELEROMETER, TEST 1-Z, RUN 2, POSITION B
4.0
3.0
2.0
1.0
0
0
50
100
150
200
250
300
350
400
450
500
REAL
FREQUENCY (Hz)

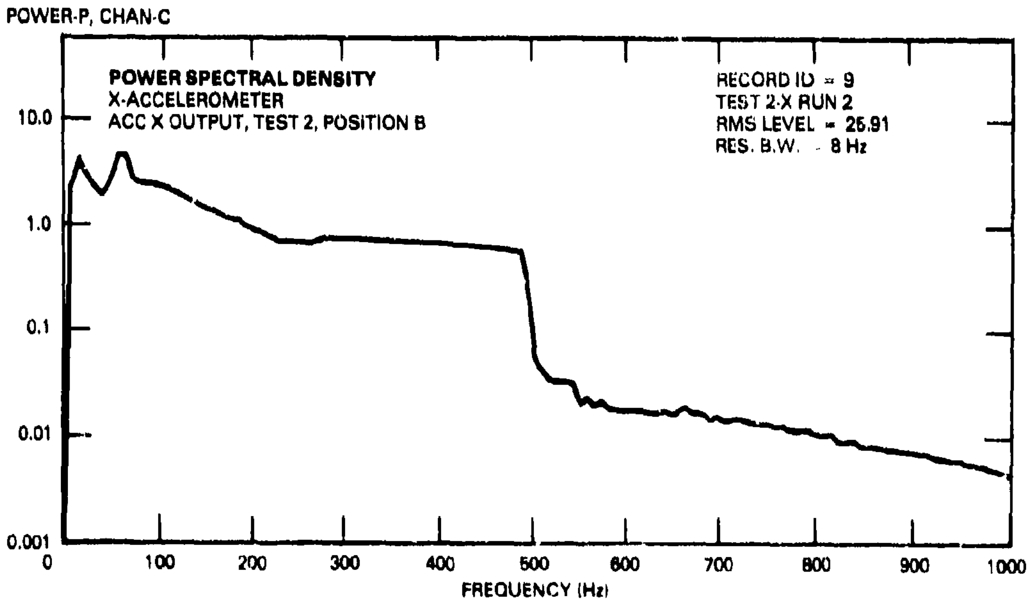

REALS
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Y-ACCELEROMETER, TEST 1-Z, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

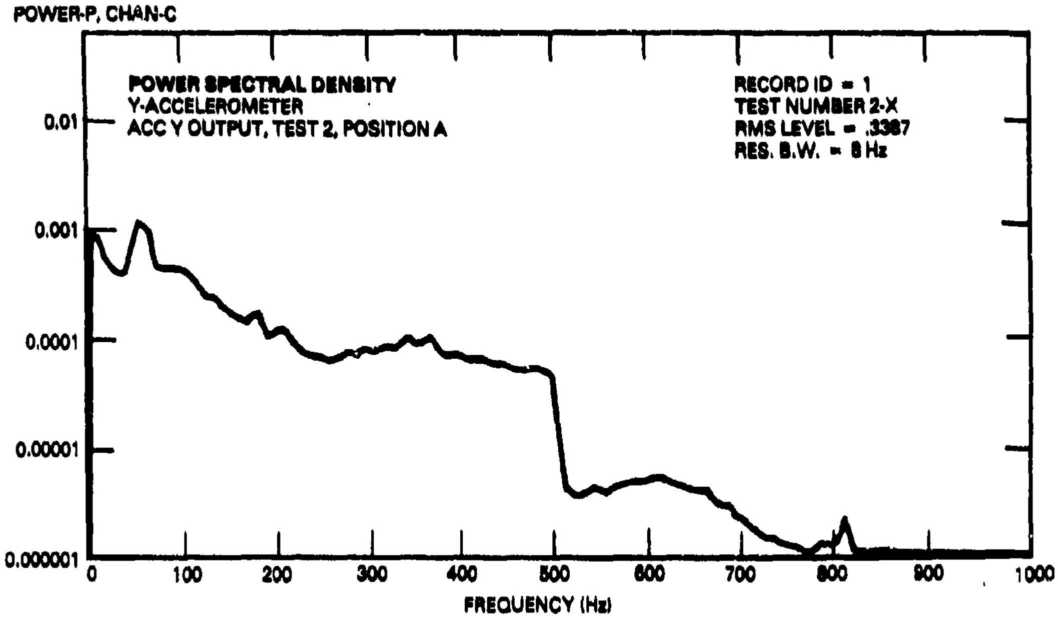

REALS
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Y-ACCELEROMETER, TEST 1-Z, RUN 2, POSITION B
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

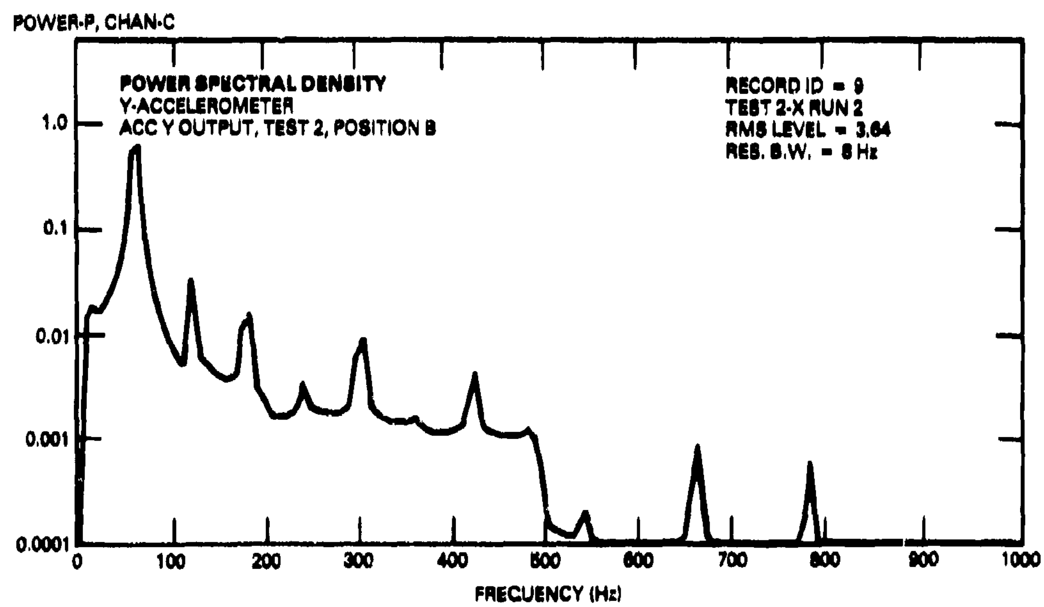

REALS
0.10
0.08
0.06
0.04
0.02
0
STRAIN GAGE, TEST 1-Z, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

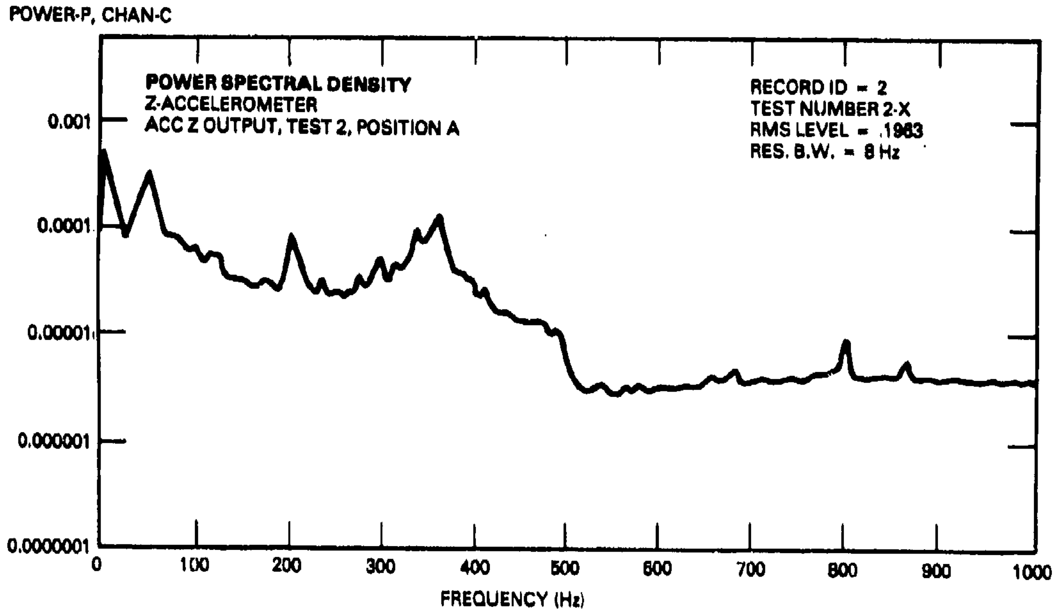

REALS
0.10
0.08
0.06
0.04
0.02
0
STRAIN GAGE, TEST 1-Z, RUN 2, POSITION B
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

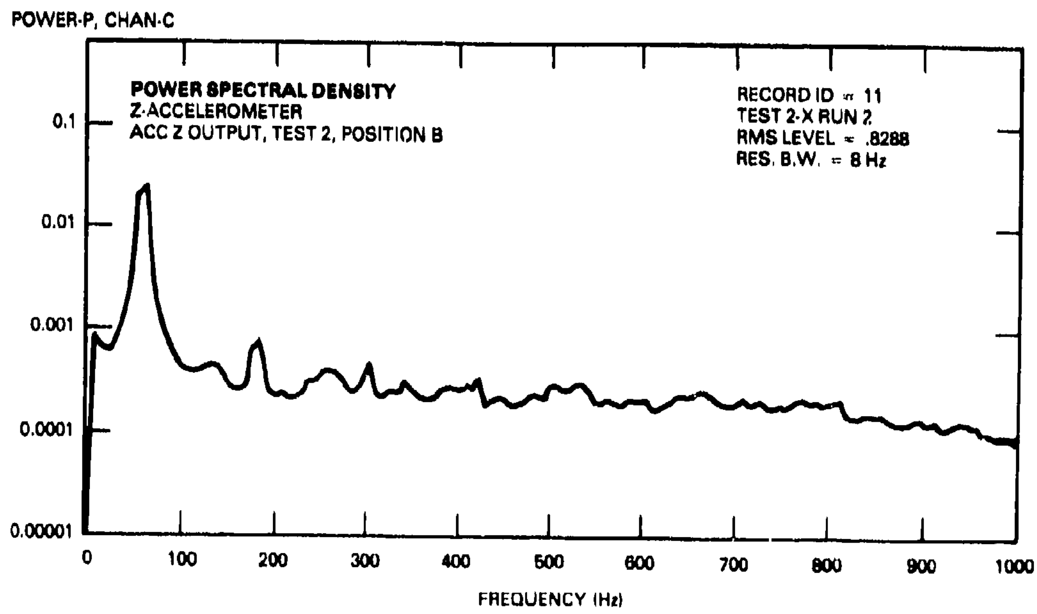

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
X-ACCELEROMETER
ACC X, TEST 2, POSITION A
RECORD ID = 1
TEST NUMBER 2-X
RMS LEVEL = 2.635
RES. B.W. = 8 Hz
0.1
0.01
0.001
0.0001
0.00001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

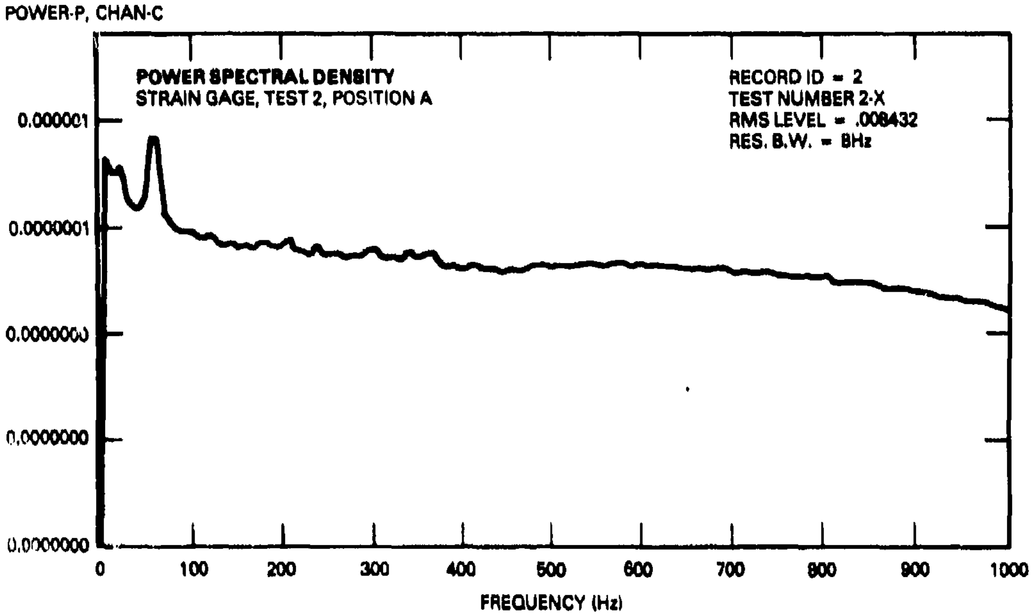

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
X-ACCELEROMETER
ACC X OUTPUT, TEST 2, POSITION B
RECORD ID = 9
TEST 2-X RUN 2
RMS LEVEL = 25.91
RES. B.W. = 8 Hz
10.0
1.0
0.1
0.01
0.001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

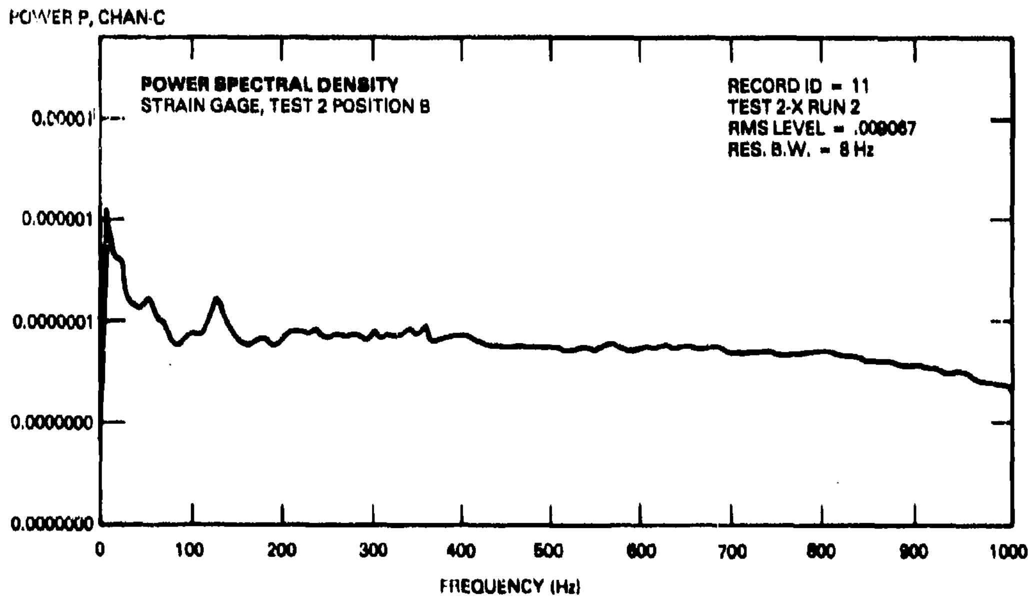

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Y-ACCELEROMETER
ACC Y OUTPUT, TEST 2, POSITION A
RECORD ID = 1
TEST NUMBER 2-X
RMS LEVEL = .3387
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

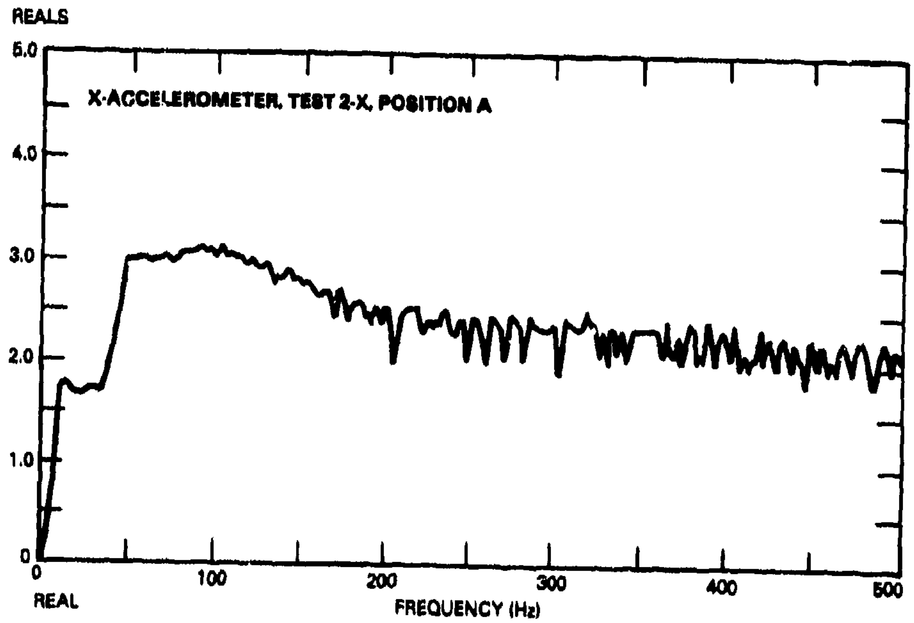

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Y-ACCELEROMETER
ACC Y OUTPUT, TEST 2, POSITION B
RECORD ID = 9
TEST 2-X RUN 2
RMS LEVEL = 3.64
RES. B.W. = 8 Hz
1.0
0.1
0.01
0.001
0.0001
0
100
200
300
400
500
600
700
800
900
1000
FRECUENCY (Hz)

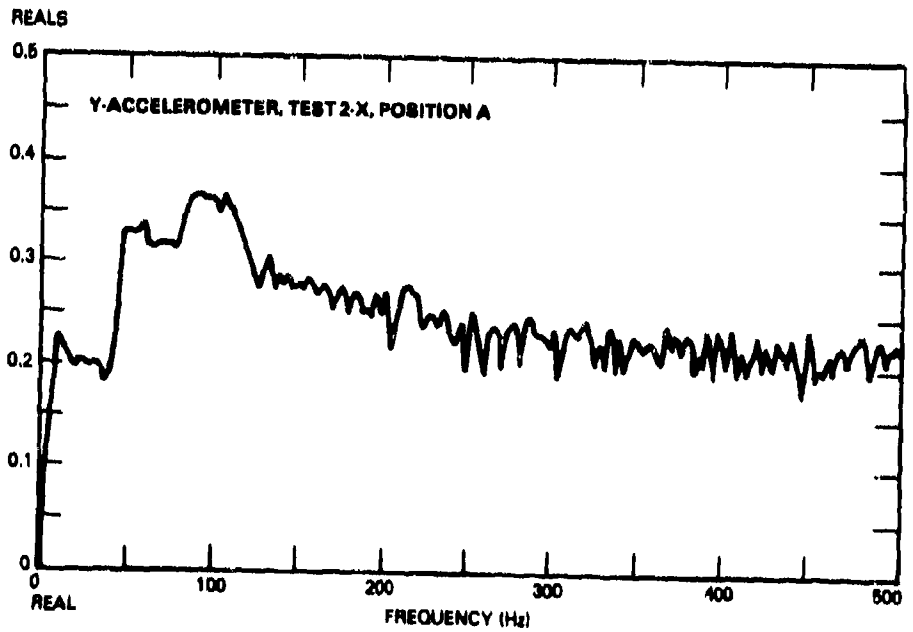

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Z-ACCELEROMETER
ACC Z OUTPUT, TEST 2, POSITION A
RECORD ID = 2
TEST NUMBER 2-X
RMS LEVEL = .1963
RES. B.W. = 8 Hz
0.001
0.0001
0.00001
0.000001
0.0000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

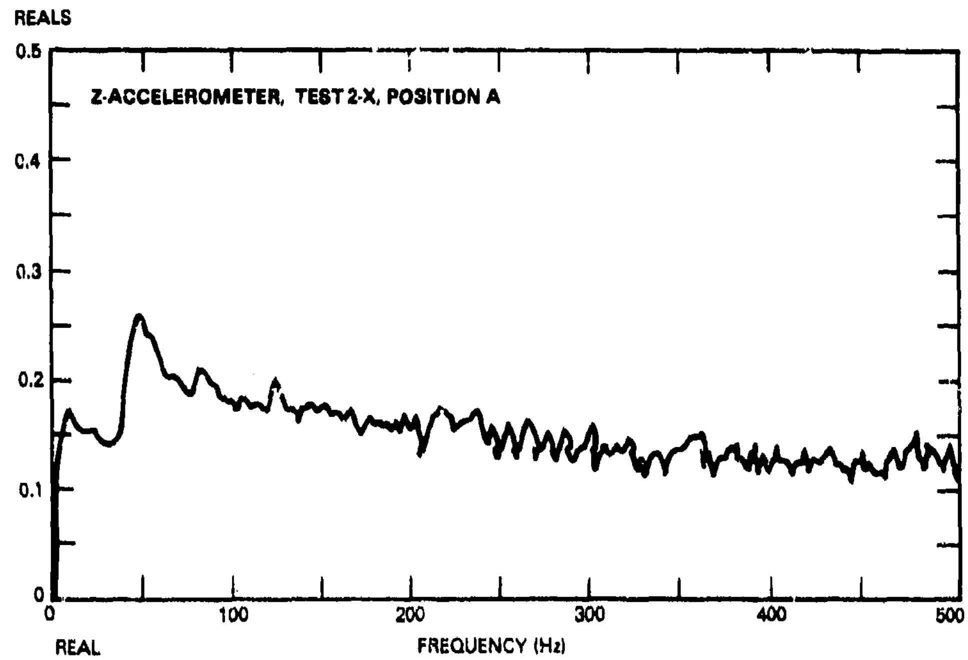

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Z-ACCELEROMETER
ACC Z OUTPUT, TEST 2, POSITION B
RECORD ID = 11
TEST 2-X RUN 2
RMS LEVEL = .8288
RES. B.W. = 8 Hz
0.1
0.01
0.001
0.0001
0.00001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

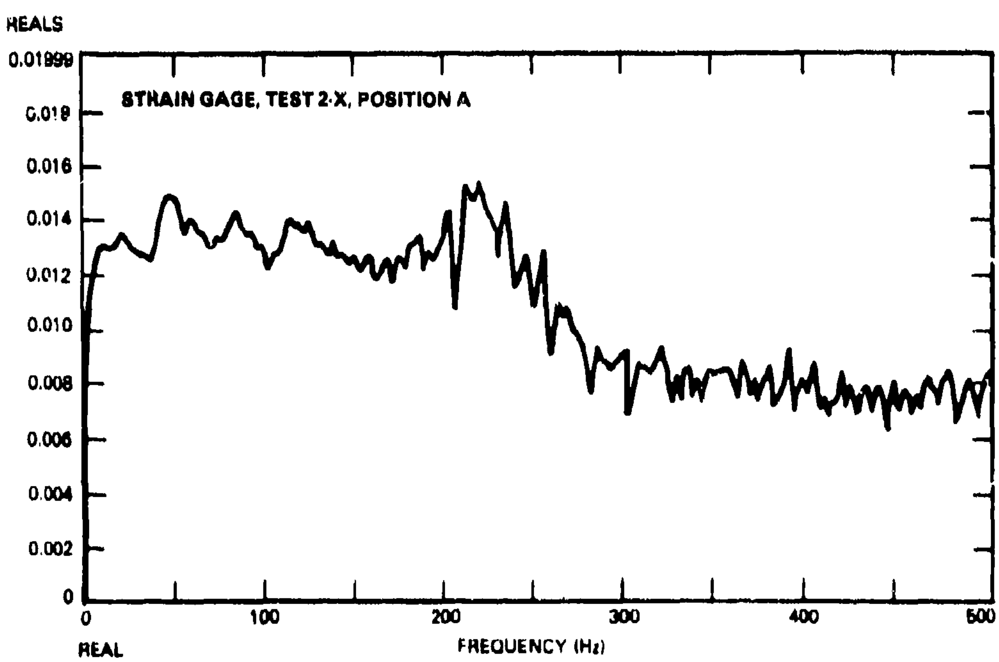

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
STRAIN GAGE, TEST 2, POSITION A
RECORD ID = 2
TEST NUMBER 2-X
RMS LEVEL = .008432
RES. B.W. = 8Hz
0.000001
0.0000001
0.0000000
0.0000000
0.0000000
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

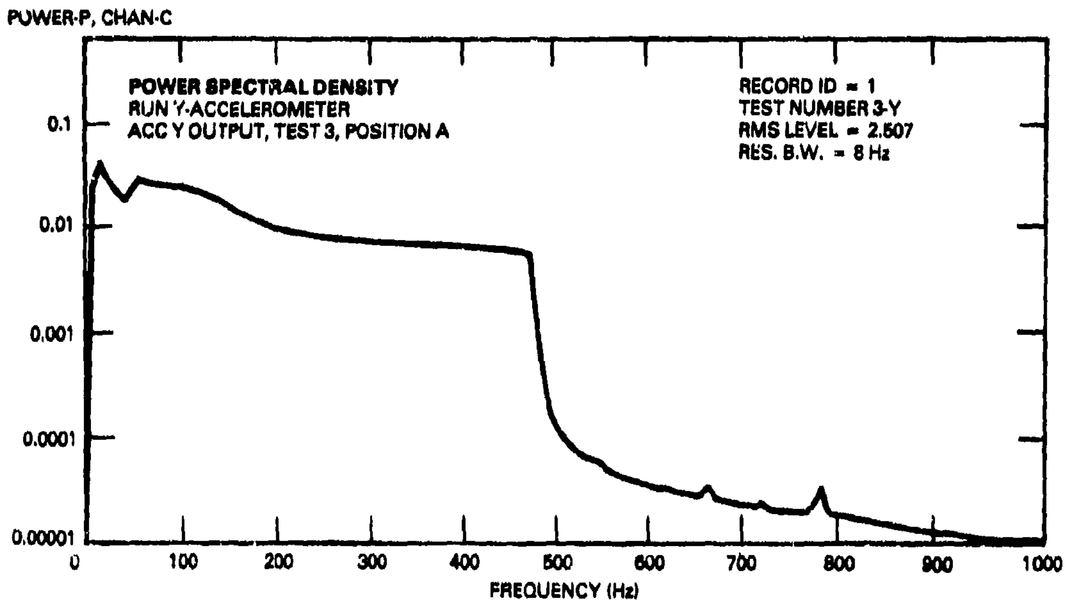

POWER P, CHAN-C
POWER SPECTRAL DENSITY
STRAIN GAGE, TEST 2 POSITION B
RECORD ID = 11
TEST 2-X RUN 2
RMS LEVEL = .009067
RES. B.W. = 8 Hz
0.000001
0.0000001
0.0000000
0.0000000
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

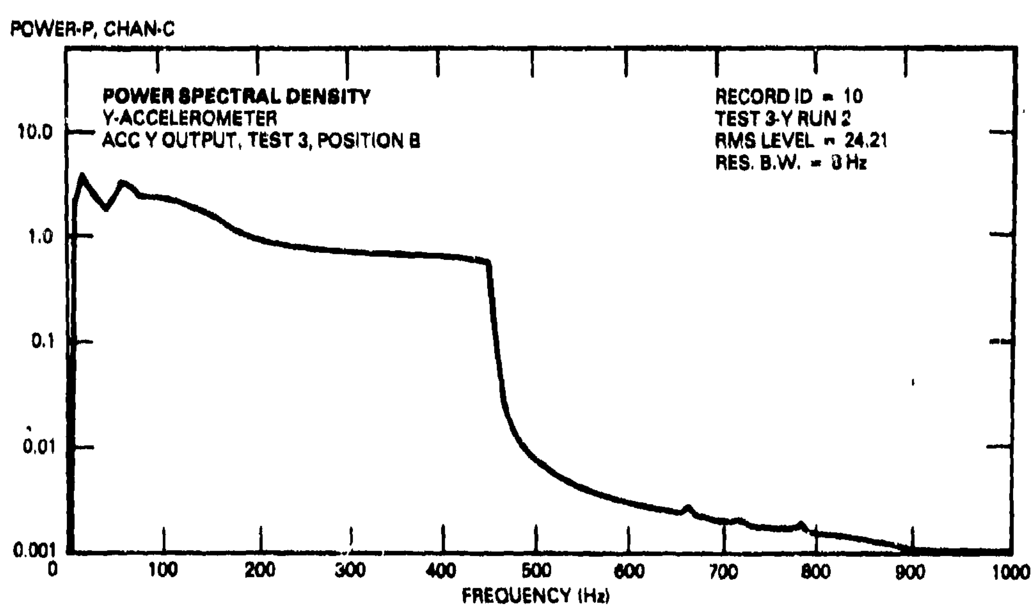

REALS
5.0
4.0
3.0
2.0
1.0
0
X-ACCELEROMETER, TEST 2-X, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

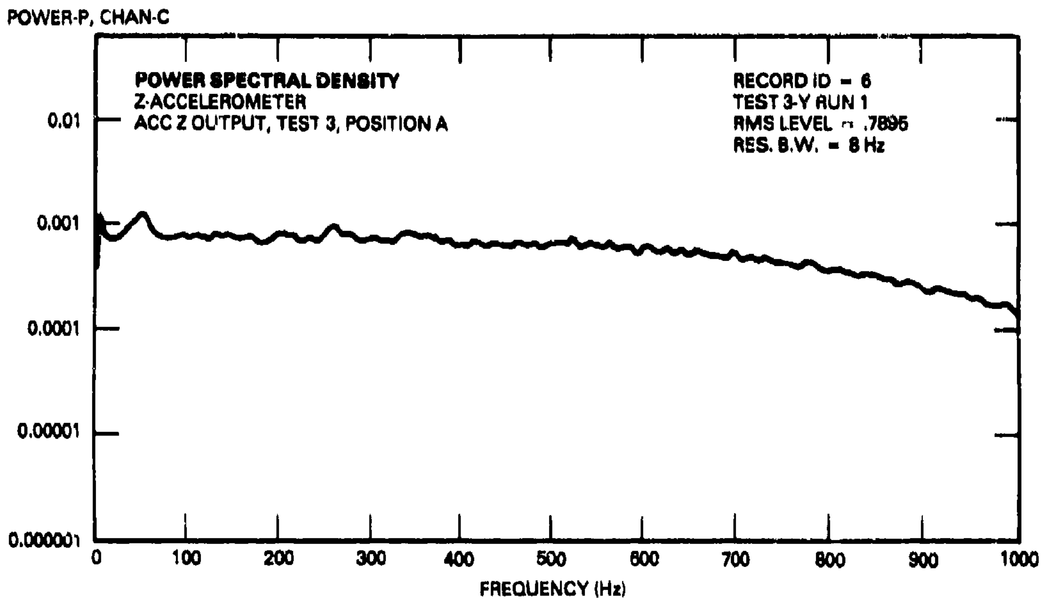

REALS
0.5
0.4
0.3
0.2
0.1
0
Y-ACCELEROMETER, TEST 2-X, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

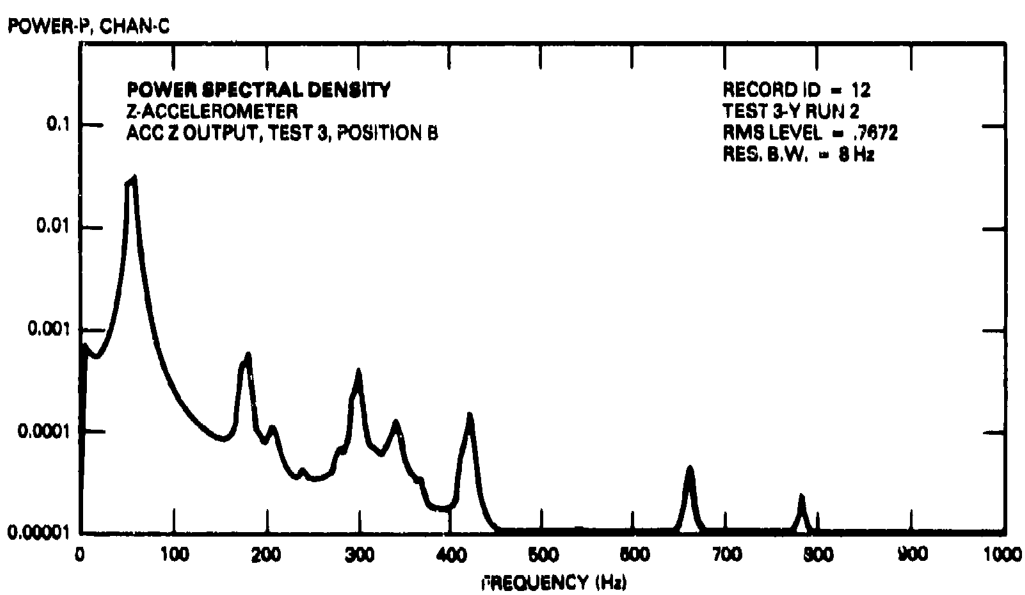

REALS
0.5
0.4
0.3
0.2
0.1
0
Z-ACCELEROMETER, TEST 2-X, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

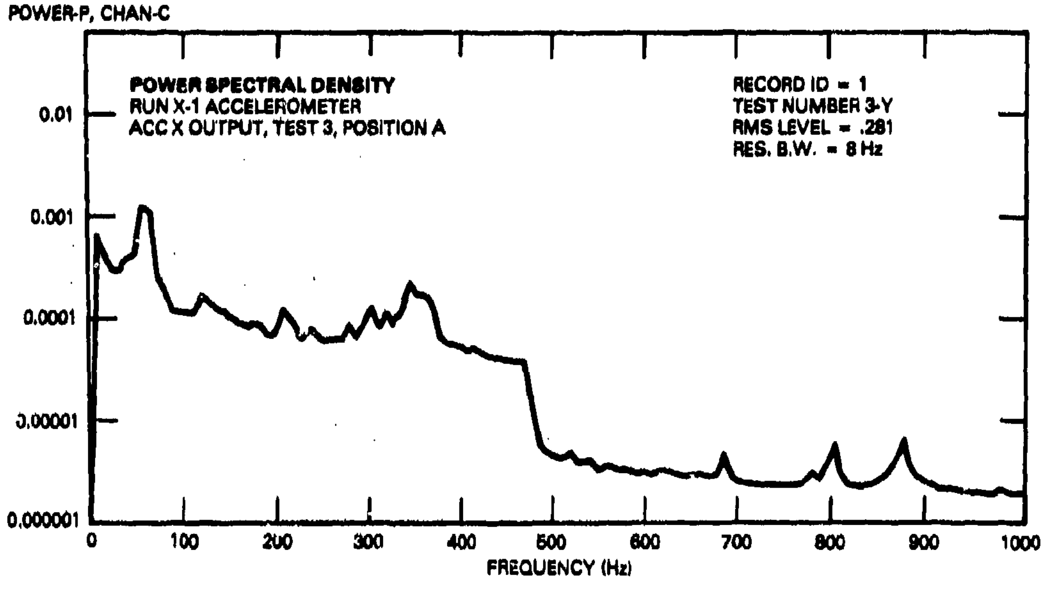

REALS
0.01999
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0
STRAIN GAGE, TEST 2-X, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

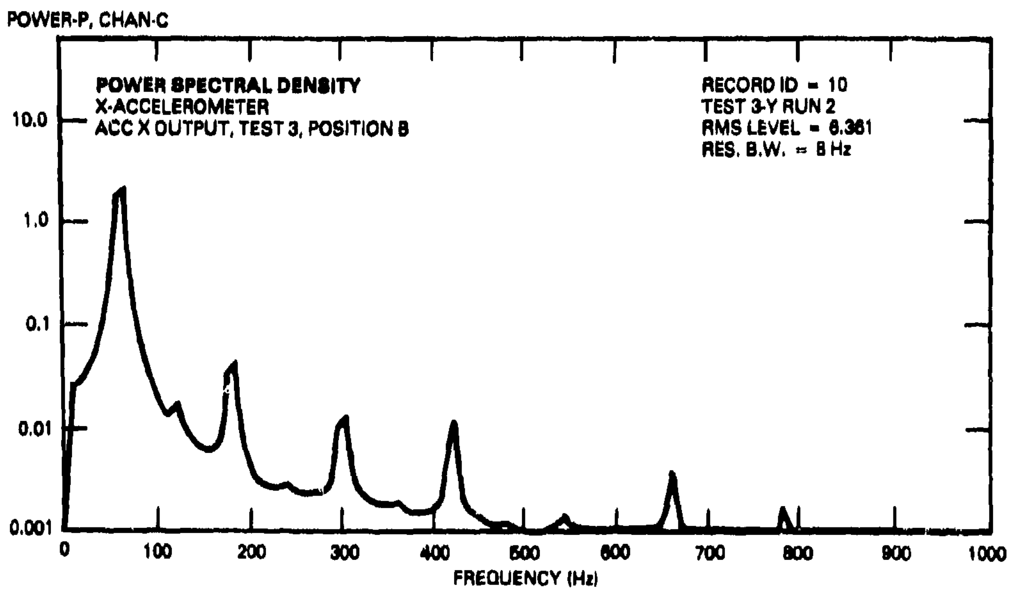

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
RUN Y-ACCELEROMETER
ACC Y OUTPUT, TEST 3, POSITION A
RECORD ID = 1
TEST NUMBER 3-Y
RMS LEVEL = 2.507
RES. B.W. = 8 Hz
0.1
0.01
0.001
0.0001
0.00001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

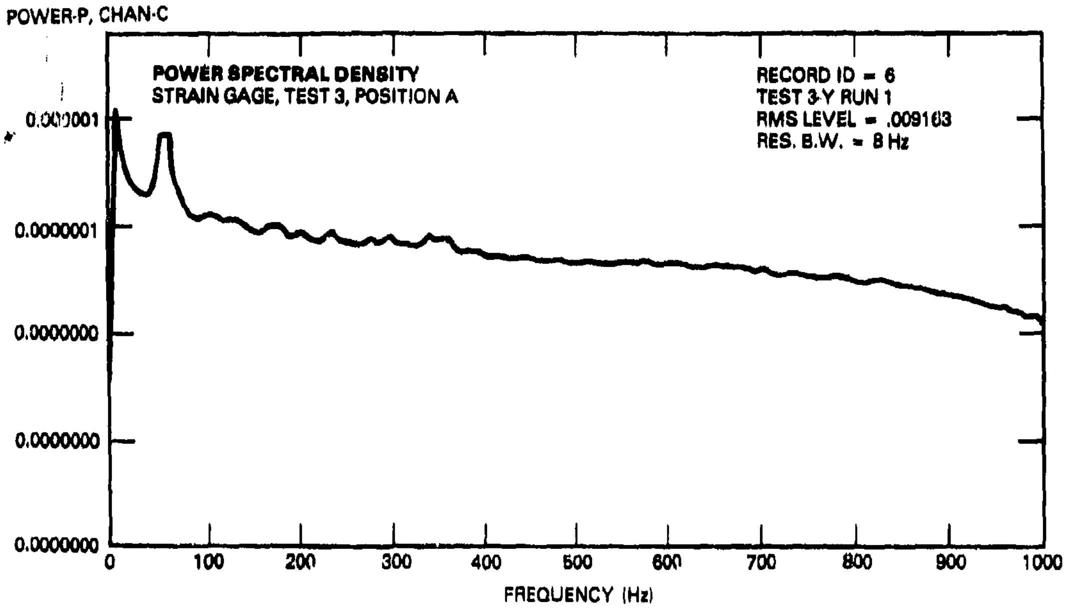

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Y-ACCELEROMETER
ACC Y OUTPUT, TEST 3, POSITION B
RECORD ID = 10
TEST 3-Y RUN 2
RMS LEVEL = 24.21
RES. B.W. = 8 Hz
10.0
1.0
0.1
0.01
0.001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

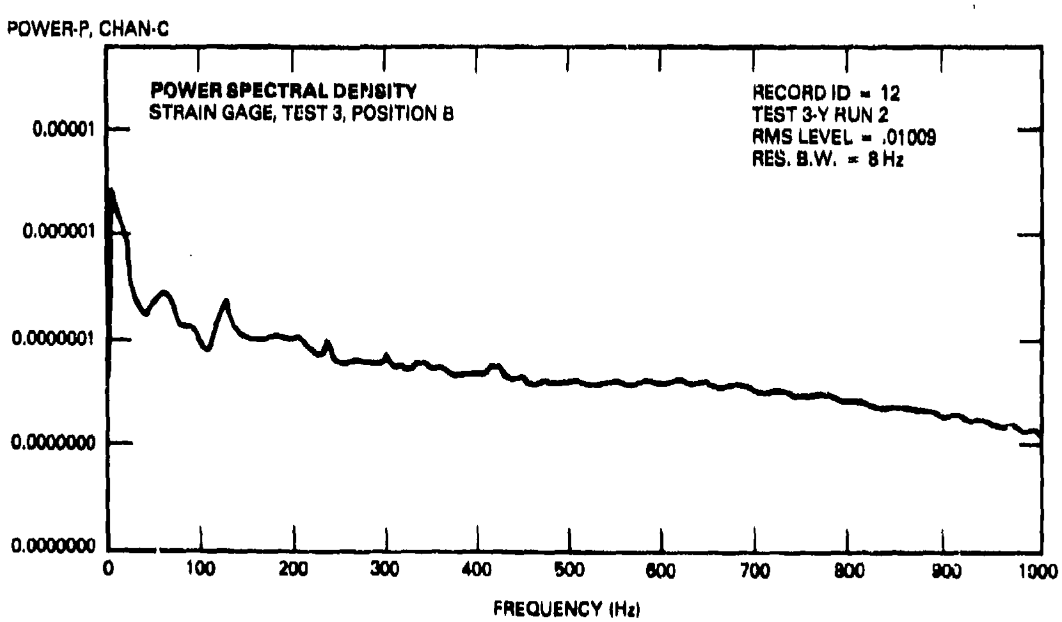

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Z-ACCELEROMETER
ACC Z OUTPUT, TEST 3, POSITION A
RECORD ID = 6
TEST 3-Y RUN 1
RMS LEVEL = .7895
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

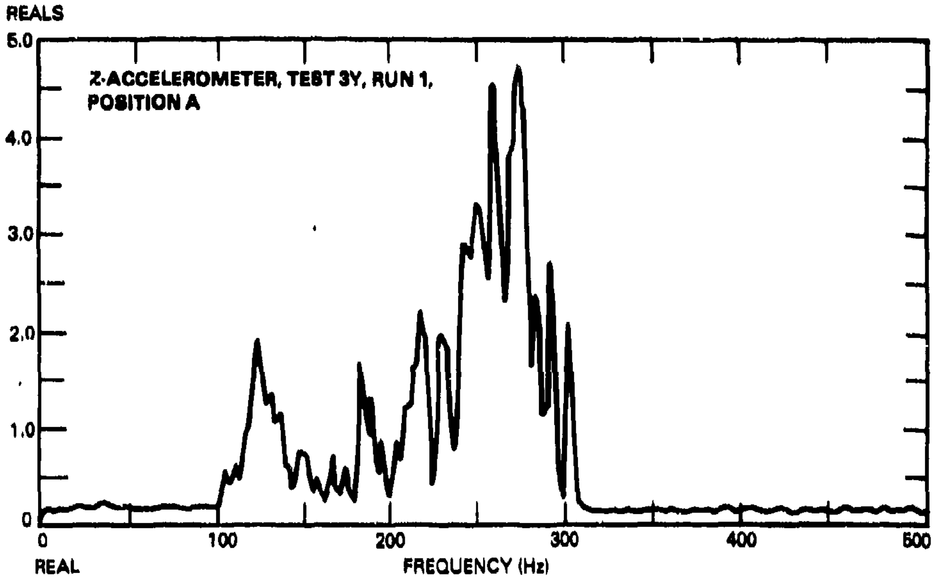

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
Z-ACCELEROMETER
ACC Z OUTPUT, TEST 3, POSITION B
RECORD ID = 12
TEST 3-Y RUN 2
RMS LEVEL = .7672
RES. B.W. = 8 Hz
0.1
0.01
0.001
0.0001
0.00001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

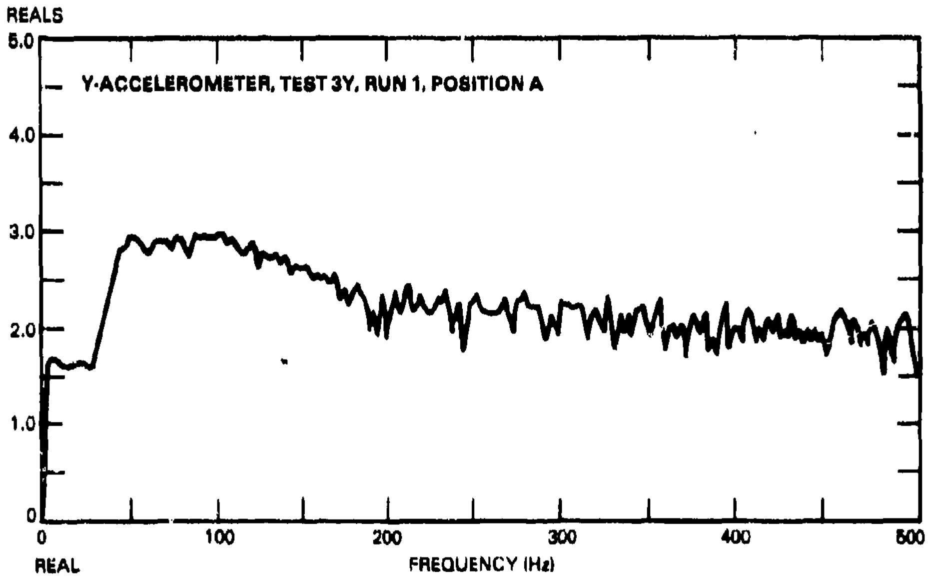

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
RUN X-1 ACCELEROMETER
ACC X OUTPUT, TEST 3, POSITION A
RECORD ID = 1
TEST NUMBER 3-Y
RMS LEVEL = .281
RES. B.W. = 8 Hz
0.01
0.001
0.0001
0.00001
0.000001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)


POWER-P, CHAN-C
POWER SPECTRAL DENSITY
X-ACCELEROMETER
ACC X OUTPUT, TEST 3, POSITION B
RECORD ID = 10
TEST 3-Y RUN 2
RMS LEVEL = 6.361
RES. B.W. = 8 Hz
10.0
1.0
0.1
0.01
0.001
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

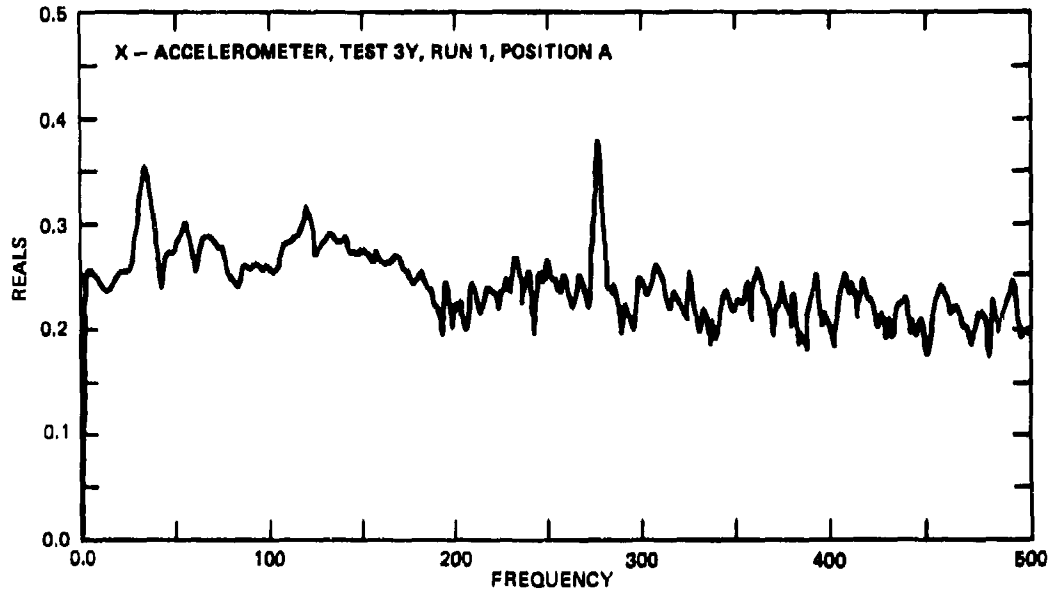

POWER-P, CHAN-C
POWER SPECTRAL DENSITY
STRAIN GAGE, TEST 3, POSITION A
RECORD ID = 6
TEST 3-Y RUN 1
RMS LEVEL = .009163
RES. B.W. = 8 Hz
0.0000001
0.0000000
0.0000000
0.0000000
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)


POWER-P, CHAN-C
POWER SPECTRAL DENSITY
STRAIN GAGE, TEST 3, POSITION B
RECORD ID = 12
TEST 3-Y RUN 2
RMS LEVEL = .01009
RES. B.W. = 8 Hz
0.00001
0.000001
0.0000001
0.0000000
0.0000000
0
100
200
300
400
500
600
700
800
900
1000
FREQUENCY (Hz)

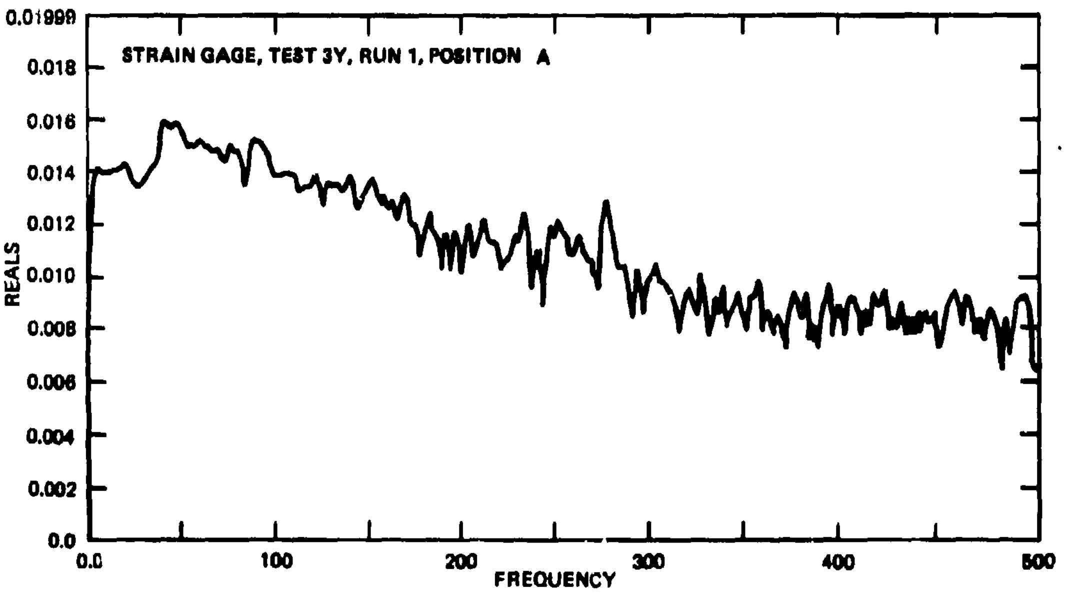

REALS
5.0
4.0
3.0
2.0
1.0
0
Z-ACCELEROMETER, TEST 3Y, RUN 1, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)


REALS
5.0
4.0
3.0
2.0
1.0
0
Y-ACCELEROMETER, TEST 3Y, RUN 1, POSITION A
0
100
200
300
400
500
REAL
FREQUENCY (Hz)

APPENDIX F



X – ACCELEROMETER, TEST 3Y, RUN 1, POSITION A
0.5
0.4
0.3
0.2
0.1
0.0
REALS
0.0
100
200
300
400
500
FREQUENCY



STRAIN GAGE, TEST 3Y, RUN 1, POSITION A
0.01999
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.0
REALS
0.0
100
200
300
400
500
FREQUENCY

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